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Fuzzy-Trace Theory and Lifespan Cognitive Development

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Abstract

Fuzzy-trace theory (FTT) emphasizes the use of core theoretical principles, such as the verbatim-gist distinction, to predict new findings about cognitive development that are counterintuitive from the perspective of other theories or of common-sense. To the extent that such predictions are confirmed, the range of phenomena that are explained expands without increasing the complexity of the theory's assumptions. We examine research on recent examples of such predictions during four epochs of cognitive development: childhood, adolescence, young adulthood, and late adulthood. During the first two, the featured predictions are surprising developmental reversals in false memory (childhood) and in risky decision making (adolescence). During young adulthood, FTT predicts that a retrieval operation that figures centrally in dual-process theories of memory, recollection, is bivariate rather than univariate. During the late adulthood, FTT identifies a retrieval operation, reconstruction, that has been omitted from current theories of normal memory declines in aging and pathological declines in dementia. The theory predicts that reconstruction is a major factor in such declines and that it is able to forecast future dementia.

Keywords

fuzzy-trace theory; developmental reversals; dual-process theories; dual recollection; Alzheimer's dementia; mild cognitive impairment

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Theories perform two principal functions in science. They explain and predict, and their accomplishments in both arenas serve as criteria for evaluating how successful they are. In psychology, the explanation function is well understood: Explanations are collections of principles or assumptions that tell us why our data are as they are. How the explanation function is implemented as an evaluative criterion is also well understood. It involves a trade-off between adequacy and parsimony; that is, theories are judged to be more successful as they explain larger numbers of findings with the same assumptions, as they explain the same findings with smaller numbers of assumptions, or both. This trade-off can be shown visually, in a vector space that is generated by an adequacy dimension and a parsimony dimension, with the explanatory success of individual theories being vectors in that space. An example is shown in Figure 1, where adequacy (number of findings

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explained) is the ordinate, parsimony (number of assumptions made) is the abscissa, and two theories appear as vectors (Theory A and Theory B). To find a theory's adequacy score, its vector is projected over to the ordinate (horizontal dotted lines), and to find its parsimony score, its vector is projected down to the abscissa (vertical dotted lines). In the example in Figure 1, Theory A is superior to Theory B because A's adequacy score (number of findings explained) is higher, and its parsimony score (number of assumptions made) is lower. It is easy to see that any theory above the diagonal is superior to any theory below it because their adequacy and parsimony scores will differ in just this way.

The prediction function is less well understood, and it is not widely grasped that prediction is more crucial than explanation. Prediction itself is merely a theory's ability to forecast new effects on the basis of its assumptions. The reason that predictive power is the more critical of the two yardsticks is that it is always possible to formulate competing explanations of the same existing phenomena that are not readily distinguishable on the basis of adequacy/parsimony trade-offs. Readers who remember their first psychology course will recall that most of the prominent phenomena that they studied (e.g., heritability of IQ, implicit racism, suggestibility of eyewitness memory, heuristics and biases in decision making) seemed to be accompanied by multiple theories that did comparable jobs of explaining it. That is the standard situation in any science, even the most advanced ones, because an explanation is just a *model* of reality, not reality itself. Of course, a model's mechanisms are motivated by evidence, but it is always possible to model reality with different assumptions. Prediction is how science escapes this *cul de sac*.

When two or more theories explain the same facts and do not differ markedly in the complexity of their assumptions, their relative predictive power refers to their respective abilities to forecast new and interesting findings. A predicted finding must, by definition, be new, but it should be interesting in the following specific sense. It ought to be unexpected on the basis on other considerations, such as other theories or of common-sense. A theory's most interesting predictions, then, violate expectations because they seem like improbable outcomes on any basis other than that theory's assumptions; the more improbable, the better. Experimental confirmation of such predictions therefore counts heavily in favor of the theories that make them.

This is by way of preamble to the theory of cognitive development that we discuss in this article, fuzzy-trace theory (FTT; e.g., Brainerd & Reyna, 2004; Reyna & Brainerd, 2011). Testing predictions that are surprising from other perspectives has been a central feature of FTT, and the present article revolves around some key examples—specifically, predictions that it makes about four of the major epochs of human development. Our overriding theme is that when it comes to generating counterintuitive predictions, a little theory goes a long way. Before getting to that, however, FTT focuses on both of the broad domains that define the study of cognitive development, memory development and the development of higher reasoning. It pays special attention to integrating theoretical principles and data from both domains and spelling out relations between them. In this sense, FTT is more akin to Piaget's approach to cognitive development (e.g., Piaget & Inhelder, 1969) than it is to other contemporary approaches. Piagetian theory spanned disparate domains of psychological developmental (learning, reasoning, memory, language, perception), whereas the rule in most contemporary theories of cognitive development is to be very domain-specific.

Originally, FTT was motivated by the fact that classical models of memory-reasoning relations could not handle several findings about how children use the contents of memory to find solutions to reasoning problems (see Brainerd & Reyna, 1990; Reyna & Brainerd, 1995). The major examples of those models were constructivism (Bransford & Franks, 1971; Piaget & Inhelder, 1973) and working-memory capacity (Case, 1985). Constructivism claimed that when the background information in reasoning problems is stored in memory, it is altered (constructed) by the same reasoning operations that are used to solve the problems, whereas working-memory capacity claimed that the retention of such information and the use of reasoning operations are both fueled by a single limited-capacity resource. Under either view, the accuracy of memory for problem information and the accuracy of reasoning ought to be strongly correlated because they both depend on the same underlying processes. That prediction, however, ran counter to a great deal of developmental data that accumulated in the 1980s and 1990s (Brainerd & Kingma, 1984). What those data showed is that accurate memory and accurate reasoning could be remarkably independent of each other and that, on occasion, accurate memory could interfere with reasoning (a finding that figures centrally in modern theories of creative production; e.g., Storm & Patel, 2014).

Ultimately, to explain such puzzling data, we adopted a dual-process model of memory, reasoning, and their development (Brainerd & Reyna, 1990, 1992; Reyna & Brainerd, 1995). The core idea was that dissociations between memory for information that is essential to accurate reasoning and reasoning itself could be explained if reasoning predominantly taps one of the dual-memory systems, whereas performance on memory tests predominantly taps the other. In particular, reasoning usually relies on a memory system that stores less precise representations of background information (fuzzy gist traces) than the system that is usually tapped by memory tests (verbatim traces). Importantly, this difference is not invariable because it was clear from the first that although the modal tendency was for reasoning problems to favor gist and for memory to favor verbatim content, both tendencies could be influenced by experimental conditions and by development. Experimentally, reasoning problems can be administered (a) that can only be solved if subjects remember the exact verbatim content of the background information (e.g., the sum of 7 + 5 + 8; Reyna & Brainerd, 1991a), or (b) that present background information for which it is difficult to avoid remembering its verbatim form (e.g., pictures; Brainerd & Reyna, 1993). Developmentally, reasoning problems that adults solve via gist might involve gists that children have not yet acquired (e.g., ratio concepts; Reyna & Brainerd, 1994), or that they have special difficulty retrieving (e.g., inclusion relations; Brainerd & Reyna, 1990b). Such variability was important theoretically because it allowed FTT to explain why memory and reasoning were so often dissociated but were sometimes associated, too: Dissociation occurs when the modal tendencies are operating, whereas association occurs when they are not—owing to factors that were not haphazard but, rather, are identified in the theory.

Naturally, some fine tuning was necessary to account for some major empirical patterns. Chief among them were that the development of gist memory is slow relative to the development of verbatim memory—that is, children's ability to store and retrieve bottom-line meaning lags behind their ability to store and retrieve surface form (Brainerd & Reyna, 1995)—and that multiple gists that vary in precision can be stored on the basis of target information—that is, there are hierarchies of gist (Reyna & Brainerd, 1991b). The first idea echoes Piaget's familiar principle (e.g., Piaget & Inhelder, 1969) that children are better able to process the perceptual qualities of events than the abstract relations that the events instantiate. Examples of hierarchies of gist include the familiar fact that for a set of numerical inputs (e.g., 9 cows, 6 horses, 2 sheep), it is possible to extract both nominal gist (e.g., “the cows are most”) and ordinal gist (e.g., “fewer sheep than horses”), as well as the fact that in written text, it is possible to extract gist at three distinct levels: word, sentence, and story (Kintsch, Welch, Smalhofer, & Zimny, 1990).

Although the dual-process conception was able to handle puzzling findings about memory-reasoning relations and their development, explanation is not prediction, and in fact, explanation is the easy part. If these ideas are correct, they ought to forecast novel findings in both the memory and reasoning spheres, including counterintuitive ones, and they ought to do that throughout the lifespan. This matter of predicting new effects over the lifespan will occupy attention in the remainder of this paper, which consists of four sections that encompass four epochs of cognitive development. Each is concerned with surprising predictions that FTT makes about memory or about reasoning—beginning with phenomena that have been subjects of extensive recent research and ending with phenomena that have been studied only within the past year or two. In the first section, we consider some counterintuitive predictions about false memory in children, which are known as developmental reversals. [Developmental reversals in different domain of memory development, forgetting, are features in another contribution to this special issue (Bauer, in press).] In the second section, we consider equally counterintuitive predictions about reasoning in adolescence, which are also examples of developmental reversals. In the third section, we consider predictions about basic retrieval processes during the age range of mainstream memory research, young adulthood. Finally, in the fourth section, we consider predictions about cognitive impairment and dementia in late adulthood. In all cases, as will be seen, the predictions fall out of the same dual-process ideas that FTT adopted to explain memory-reasoning relations. To the extent that such predictions are confirmed, explanatory power is then enhanced because in Figure 1, as the score on the adequacy axis increases, the score on the parsimony axis remains fixed, and the theory's vector lengthens and rotates to the left.

Childhood: Developmental Reversals in False Memory

The Law and Children's Memories

Children's false memories have been among the most widely studied phenomena in memory development. Although such distortions are of great theoretical interest, there is an applied dimension memories that supplied the original impetus for research: legal evidence. In legal cases, the evidence that determines guilt or innocence comes chiefly from memory reports, in the form of the recountings of events by witnesses and victims. This is true even for crimes that involve the most serious punishment, such as capital murder (Brainerd, 2013). Those recountings are first provided informally to investigators or attorneys and are later provided as sworn testimony. Such evidence is accurate only to the extent that memory reports are accurate, and if recountings include events that did not happen (e.g., the defendant was holding a weapon) or that happened in a different way (e.g., the defendant was holding a screwdriver rather than a knife), those errors are normally difficult to disprove with physical forensic evidence (Brainerd & Reyna, 2005). Consequently, when researchers have reviewed established cases of false conviction, certain types of false memory reports are the predominate causes (e.g., Kassin, 2005; Wells, Small, Penrod, Malpass, Fulero, & Brimacombe, 1998).

For more than a century, researchers have been proposing that children's reports are far more likely to be infected by false memories than those of adolescents or adults (Binet, 1900), to the point where children's memories may be utterly prejudicial as evidence in legal proceedings (Whipple, 1909). Until recently, this was not a problem in the U.S. because most jurisdictions excluded such evidence by statute (McGough, 1993). In the 1970s, however, that situation changed pursuant to the realization that some crimes cannot be prosecuted without such evidence because children are usually the only witnesses, and in some instances, they are both witnesses and victims. The key examples are domestic violence, home-based criminal activity (e.g., drug production), and child abuse and neglect. Child sexual abuse, in particular, supplied the motivation for altering exclusionary statutes. Data reported by the American Association for Protecting Children seemed to show that from 1976 to 1986, cases of child sexual assault had risen from under 20,000 to nearly 140,000, which suggested an urgent need to prosecute and punish child sexual offenders. As children and perpetrators are usually the only witnesses to these horrific crimes, prosecution is normally impossible without children's evidence. Not surprisingly, exclusionary statutes began to vanish, and eventually, the broad admissibility of evidence from children's testimony received federal sanction in Federal Rules of Evidence 601 (The Committee on the Judiciary of the House of Representatives, 2006), which instructed courts to allow juries to decide for themselves how much weight to give to such testimony—just as they do for any other form of evidence.

By the early 1990s, prosecution of child sexual abuse on the basis children's allegations had become widespread. Many defendants had been convicted who otherwise would not have been charged, let alone tried, for such crimes. Simultaneously, however, a problem surfaced that was foreshadowed by historical concerns about children's false memories. It consisted of some prosecutions that had received heavy media attention, in which children had accused defendants of weird and improbable acts of abuse. To the average person, it seemed more likely that the accusations were fantasy than that the defendants had committed those acts—hence, the media attention (Ceci & Bruck, 1995).

The textbook examples were *State of California v. Buckey* (1990) and *State of New Jersey v. Michaels* (1988). In *Michaels*, a preschool teacher was convicted of over 100 counts of sexual abuse of 20 children and was sentenced to a long prison term. However, many of the children's allegations were bizarre. To illustrate, it was alleged that the teacher had spread peanut butter on their genitals and had played the piano while nude. Following the conviction, an ad hoc committee of memory researchers reviewed the evidence and concluded that there were strong indications that the children's reports were infected by false memories. The committee's analysis was submitted to the New Jersey Supreme Court in an *amicus* brief, and the court ultimately reversed the conviction (*State of New Jersey v. Michaels*, 1994). By that time, however, the defendant had been imprisoned for more than four years.

In *Michaels*, *Buckey*, and similar cases, convictions were overturned or prosecutions were challenged on the ground that children's allegations were likely to be tainted by false memories. The predictable result was the generation of an extensive literature that documented children's false memories under controlled conditions, that identified factors that cause such distortions, and that measured age variability in false memory (for reviews, see Brainerd & Reyna, 2005; Bruck & Ceci, 1999; Goodman, 2006; Quas, Qin, Schaaf, & Goodman, 1997). That literature has been put to some important uses. It has supplied the scientific underpinning for model child interviewing protocols; procedures that investigators use with child witnesses to maximize the yield of true memories and minimize the yield of false ones (for a review, Poole & Lamb, 1998). In addition, that literature provides the grounding for testimony on the reliability of children's memories by expert scientific witnesses. Many findings about conditions that distort children's memories have figured in expert testimony, but the most prominent one are overall age trends in false memory. There, the scientific picture seemed clear and consistent: False memories decline with age, as Binet (1900) and other early researchers had claimed, and age is the single best predictor of differences in amounts of false memory (Ceci, Papierno, & Kulkofksy, 2007). Those declines have been carefully documented in memory suggestion experiments, which imitate the leading questions that are used in police interviews of witnesses—the manipulative interviewing practices that first fomented scientific interest in children's false memories (e.g., Bjorklund et al., 2000; Marche, 1999)—and also in experiments that measure spontaneous false memories, in which distortions occur without the aid of suggestion (e.g., Brainerd & Reyna, 1996; Pipe, Gee, Wilson, & Egerton, 1999).

The age-decline pattern has direct implications for expert testimony on the reliability of child memory reports. In particular, it supplies a scientific foundation for challenging such reports and the competence of child witnesses to testify, on the ground that any report from a child is more likely to contain false memories than a corresponding reports from an adolescent or adult. For jurors, the age-decline pattern leads to the simple rule that adolescents' and adults' evidence is inherently more reliable than children's. This inherent reliability difference has taken on the status of settled law. Some courts have even ruled that it has risen to the level of common-sense knowledge; that jurors already comprehend this reliability difference, and therefore, expert witness are not needed to document it (McAuliff, Nicholson, & Ravanshenas, 2007).

Developmental Reversal Predictions

The odd thing is that it was always clear, on theoretical grounds, that the age-decline pattern could not possibly be as universal as the data or courtroom testimony made it seem. To see why, it is necessary to sketch FTT's account of false memory, which is just an application of the dual-process ideas that were mentioned earlier. We shall see that those ideas supply an algorithm that specifies conditions under which false memories should *increase* with age, but, it is necessary to briefly consider what the phenomenon of false memory is—that is, what is actually measured.

The most common false memories, and the ones that are of critical concern in legal cases, are *semantic* false memories. Their key feature is that although the remembered information is false, its meaning—its gist—is consistent with the actual events. To take a forensic illustration, suppose that a robbery witness falsely identifies a photograph of a young Hispanic male as the robber. In most documented instances of this error, the actual robber was a young Hispanic, so that the memory report was false but it matched the age/gender/ethnicity gist of the robber (although cross-racial identification is known to be impaired and accuracy varies across individuals; e.g., Henry & Gudjonsson, 2004). To take another forensic illustration, suppose that during an interrogation a robbery suspect states that he entered a convenience store where a robbery occurred at 11:30 p.m. on Sunday, when actually he was there at 10 p.m. on Saturday. Although the time and day are wrong, they match the gist of the correct time (“late evening”) and day (“weekend”).

FTT's explanation of semantic false memories runs as follows (see Brainerd & Reyna, 2005). Subjects (e.g., witnesses and victims) store distinct verbatim and gist representations of events, and those representations typically affect true and false memory in opposite ways when they are retrieved. Verbatim traces capture exact details of experience—its actual surface form. Thus, in the above examples, if the witness had retrieved verbatim traces of the robber's facial appearance or the suspect had retrieved verbatim traces of when the convenience store was visited, they would, of course, support identification of photographs of the actual robber and reports of the correct time and day. However, they would also support *rejection* of photographs of innocent suspects and of suggestions about wrong times or days, a process known as recollection rejection (Brainerd, Reyna, Wright, & Mojardin, 2003). On the other hand, suppose that the witness retrieved gist traces of the robber's face or the suspect retrieved gist traces of the time/day of the convenience stored visit. Like verbatim traces, gist traces support correct identification of the actual robber and correct reports of time/day because the gist of experience matches, but for the same reason, it supports false identification of innocent suspects and false reports of incorrect times/days. The denouement is that levels of semantic false memory depend on the relative incidence of verbatim and gist retrieval, which is influenced by many task factors, such as the direction in which retrieval cues are slanted or the respective forgetting rates of verbatim and gist traces (for a review, see Brainerd & Reyna, 2005). When task factors are held constant, individual differences in false memory, such as developmental differences, will depend on individual differences in verbatim and gist retrieval, a matter we now consider.

The events of our lives, including those that are central in legal cases, are rich in meaning and in meaning connections. A general finding of research, noted earlier, is that gist memory tends to lag verbatim memory developmentally. Here, there is a vast literature, reaching back decades, showing that children's tendency to spontaneously store simple event meanings that are already known to them (e.g., that a horse is an animal) and to connect then over multiple exemplars (e.g., that a horse, cow, and goat are all animals) develop quite slowly—throughout early childhood, later childhood, adolescence, and into young adulthood (for a review, see Schneider, 2014). Extensive evidence comes from experiments on the development of semantic organization in recall, where children of different ages are exposed to collections of familiar words, or pictures, objects, or events. There, gist memory for items' meaning content and for meaning relations among items are measured, with memory for taxonomic meanings have been especially well studied. When adults perform these simple tasks, they exhibit excellent recall of meaning content and meaning relations, and in particular, their recall displays three properties: It is better when targets share salient semantic relations than when they do not, targets are recalled in bursts of same-meaning items (known as semantic clustering), and total recall increases as semantic clustering increases. Adults, on this showing, are good at storing events' meaning content and connecting meaning across events. Surprisingly, considering the simplicity of such tasks, children are not. Few children display any of these very elementary semantic effects before late childhood or adolescence. In the absence of explicit cues to process meaning, and sometimes even in the presence of such cuing (e.g., Howe, 2008), semantic processing is quite limited in children. Thus, the key memory variable that supports semantic false memory, retrieval of gist traces, seems to improve rather dramatically between childhood and young adulthood. The prediction of developmental reversals in false memory is then straightforward, as is the algorithm that we noted earlier.

The algorithm refers to tasks that meet just two conditions. The first is that the false memories that subjects exhibit match gists that we know are easier for older children and adolescents to store and retrieve than for younger children. Second, the corresponding false memories are hard to edit out of memory reports by relying on verbatim traces of actual events. Although this second condition might not seem important, it is crucial: Verbatim memory is developing, too, and those improvements could be exploited to neutralize the increases in false memory that would otherwise follow from improvements in gist memory (Brainerd, Stein, & Reyna, 1998). Owing to the many developmental studies that have identified age *increases* in false memory, we already know that various forms of false memory apparently do not satisfy one of both of these conditions. The question is whether there are any other forms that clearly satisfy both conditions, and hence, can be used to test the prediction algorithm.

Developmental Reversal Data: DRM and Other Tasks

The type of task we seek is one that exposes subjects to familiar items that share some salient meaning and, then, measures false memory for other familiar exemplars of that meaning. Such tasks satisfy the algorithm because false memory depends on storing meaning and connecting it over items, something that improves with age and that children have difficulty with, and the fact that many examples of a meaning are presented makes it hard for age increases in verbatim memory to neutralize age increases in false memory. Luckily, we need not look far for such a task because the most widely used paradigm for studying adult false memory—the Deese/Roediger/McDermott (DRM; Deese, 1959; Roediger & McDermott, 1995) illusion—is just such a procedure. There, are several other tasks that satisfy the algorithm, too, which we will discuss later on, but for now, we will confine attention to this one, very simple, paradigm.

Subjects study a list of 12-15 words that is from word association norms by selecting a word that has many associates in those norms, such as *city*, *fruit*, *king, needle*, or *window*, and using the norms to identify its 15 most common associates. For *window*, say, they are door, glass, pane, shade, ledge, sill, house, open, curtain, frame, view, breeze, sash, screen, and *shutter*. The list is then presented one word at time, and afterward, subjects are asked to recall the words or to respond to an old/new recognition test composed of list words and distractors. The words that are used to create these lists, which are called critical distractors or critical lures, are not on the lists. Nevertheless, subjects falsely remember them at high levels after studying the lists. For example, following the *window* list, college students falsely remember studying *window* 65% of the time on recall tests and 84% of the time on recognition tests (Roediger, Watson, McDermott, & Gallo, 2001).

A great deal is known about factors that affect false memory on this task, including individual differences (e.g., Gallo, 2010). With respect to experimental conditions, two overall themes are that manipulations that encourage subjects to process the semantic gist list words (e.g., deep processing instructions, gist cuing) increase false memory, whereas manipulations that encourage subjects to process surface details (e.g., shallow processing instructions, presenting pictorial versions of lists) decrease it. On the individual differences side, characteristics that reduce semantic processing, such as reading comprehension deficits (Weekes, Hamilton, Oakhill, & Holliday, 2007) and autism spectrum disorders (Bowler, Gardiner, Grice, & Saavalainen, 2000), reduce the DRM illusion. Children should be another population of this sort because, according to studies of semantic organization in recall, their storage and connection of meaning are limited, relative to adolescents and adults.

Beginning with some experiments by Brainerd, Reyna, and Forrest (2002), more than 60 studies have been published in which developmental increases in the DRM illusion have been detected between children of different ages, between children and adolescents, or between children and young adults (for a review, see Brainerd, Reyna, & Zember, 2011). Brainerd et al. (2011) also noted that the *net accuracy* of memory—the ratio of the probability of correctly remembering any word on a DRM list divided by that probability plus the probability of falsely remembering the critical distractor, actually declines between early childhood and young adulthood. This developmental reversal pattern is so counterintuitive (memory should be getting better, not worse, with age) that, of course, the initial response was skepticism. Consequently, several studies appeared that focused on whether the pattern might not be replicable (e.g., Howe, Cicchetti, Toth, & Cerrito, 2004), or whether it was an artifact of failure to control some extraneous variable (e.g., children may not understand some of the words on DRM lists; Metzger, Warren, Price, Reed, Shelton, & Williams, 2008). The skepticism proved to be unwarranted because the pattern was replicated repeatedly and was not found to be due to any of the artifacts that were proposed.

Once a consensus had formed on those points, attention turned to tying developmental changes in specific underlying processes to age increases in the DRM illusion. Here, a pair of themes emerged that resemble the two that were mentioned in connection with adult DRM research—namely, the fact that semantic processing foments the illusion and verbatim processing decreases it. Concerning the former, there are various manipulations (e.g., cuing the gist of DRM lists) that should reduce age differences in semantic processing by increasing it more in younger than in older subjects, and as FTT would predict, such manipulations cause age differences in the DRM illusion to shrink (e.g., Brainerd, Forrest, Karibian, & Reyna, 2006). Concerning the latter, there are various other manipulations (e.g., presenting DRM lists as anagrams or as pictures) that should reduce age differences in semantic processing by decreasing it more in older than younger subjects, and as FTT would also predict, those manipulations cause age differences in the DRM illusion to shrink (e.g., Holliday, Brainerd, & Reyna, 2011). At this point, then, developmental reversals in false memory are well established in DRM studies, and they have been tied to both of the conditions that are specified in the algorithm that predicts them.

Considering that the DRM procedure is simple and that produces such stable age trends, it is hardly unexpected that it has been implemented in most developmental reversal studies. However, there are other paradigms that satisfy the algorithm and that should also display developmental reversals. Several of these other connected-meaning paradigms have been investigated and have produced the predicted pattern. Examples include false memory for taxonomic word lists (Brainerd & Reyna, 2007), for pictures of faces expressing emotions (Fernandez-Dols, Carrera, Barchard, & Gacitua, 2008), for statements in narratives (Lyons, Ghetti, & Cornoldi, 2010), for events in staged activities (Odegard, Cooper, Lampinen, Reyna, & Brainerd, 2009), for lists of emotional words (Howe, 2007), and for suggestions about prior experiences (Principe, Guiliano, & Root, 2008). Depending on the study, developmental reversals in false memory have been identified for various segments of the preschool-to-young-adult age range. Thus, the pattern is not confined to the DRM illusion, and befitting the historical connection between false memory research and the law, it has been detected with procedures that have been used in the literature of forensic psychology (e.g., Fernandez-Dos et al., 2008; Principe et al., 2008).

Summary

FTT makes surprising predictions about memory distortion in childhood. It predicts age increases in some types of false memories that are common in adults and adolescents, even to the point that the net accuracy of children's memories can exceed adults'. This is because the distortions in question are rooted in semantic abilities—particularly, the spontaneous extraction and connection of meaning—that are more limited during childhood than later on. Although the predictions are counterintuitive, they have been confirmed in many developmental studies, using paradigms that range from laboratory word lists to forensically-oriented tasks.

Adolescence: Developmental Reversals in Reasoning

During adolescence, the same theoretical ideas predict other surprising developmental reversals, which involve reasoning. The received developmental wisdom about reasoning is for it to become more accurate, logical, and rational with age, and hence, predictions that it becomes less so are automatically counterintuitive. FTT not only makes such predictions in some important situations that involve uncertainty and risk, but it anticipates that adolescents' reasoning can be more "rational" than adults' and that this is a prime factor in their risky behavior (e.g., Reyna, Estrrada et al., 2011). Before getting to that, however, we consider some background on risky behavior in adolescence and experimental procedures for studying reasoning about risk.

Background

Adolescence is traditionally viewed as an era when dangerous, risky behavior peaks. Examples include illegal use of alcohol and drugs, carrying weapons, reckless driving, shoplifting, unprotected sex, smoking, fighting, and joining gangs. The data confirm this familiar idea (Centers for Disease Control and Prevention, 2004). For example, Figure 2 contains U.S statistics on arrests for serious crimes by age, from 12 to 65, where it can be seen that just before adolescence, the arrest rate is near-floor. Then, it jumps sharply and continues to rise steeply until it peaks in the late teenage years. As people enter the 20s, the arrest rate drops as just sharply as it rose during adolescence and continues to drop throughout early, middle, and late adulthood.

Experts often cite two potential causes of high levels of adolescent risky behavior (Reyna & Farley, 2006). First, adolescents, as compared to children, have greater exposure to circumstances in which there are opportunities for risky behavior (Andrews, Hampson, Barckley, Gerrard, & Gibbins, 2008; Reyna & Rivers, 2008): They attend social events with decreased adult supervision; they drive automobiles; they date; and they have increased access to alcohol. However, this does not explain why risky behavior would be so much higher during adolescence than immediately thereafter, considering that young adults have even greater exposure to those same situations and others besides. A second reason is needed, and here, the modal thesis is that developmental characteristics of adolescents render them especially susceptible to the temptations of risk, particularly social/emotional characteristics as distinct from cognitive ones (Steinberg, 2004). For instance, risky behaviors are rewarding, and a common idea is that adolescents are inherently more *sensitive* to the benefits of reward—in effect, they are reward seekers—than young adults are; the rewarding properties of, say, alcohol or sex loom larger to a 16-year-old than a 26-year-old. Inhibition is another example of the modal thesis. Inhibition is, of course, important when it comes to suppressing urges to take unhealthy risks, and there is research that ties individual and developmental differences in inhibition to the frontal and prefrontal regions of the brain (e.g., Galvan et al., 2006). During maturation, those regions are among the last to myelinate, a finding that was cited by the U.S. Supreme Court when it banned of capital punishment with adolescent defendants.

FTT hypothesizes that there are also key *cognitive* differences between adolescents and young adults that increase risky behavior. Those cognitive differences are sources of counterintuitive predictions about adolescent reasoning, but in order to test such predictions, experimental tasks that measure reasoning under conditions of risk and uncertainty are needed. Three examples are shown in Table 1, decision framing, the Allais paradox, and the Centipede game. In these tasks, adult subjects exhibit irrational reasoning, and in the case of the Allais paradox and the Centipede game, make decisions that run counter to rational self-interest. Decision framing has been more extensively studied that the other two, with published experiments numbering in the hundreds. Subjects are confronted with pairs of prospects (about disease treatments in Table 1), with the outcome of one being certain and the other risky. The paired choices are phrased in contrasting ways, as gains (A and B) or as losses (C and D). Even a superficial consideration of the numerical values establishes there is no choice to be made because all four prospects yield the same outcome. (In Table 1, the outcome is always 200 will live and 400 will die.) Thus, one logical, rational decision is "no preference" in both the gain and loss frames. Another defensible set of preferences is to be consistently risk avoiding or consistently risk seeking. That is not how adults behave, and instead, their reasoning is illogical or inconsistent (e.g., Tversky & Kahneman, 1986): They have strong preferences with both pairs, and one is the opposite of the other; they prefer option A (the certain one) in the gain frame, but option D (the gamble) in the loss frame.

Turning to the Allais paradox, Decision 1, is a choice between a sure thing and a gamble. The expected payoffs are $1,000,000 for the sure thing and $1,390,000 for the gamble, so the latter is the logical choice. However, adults strongly prefer the former, violating what the numbers say and what rational self-interest says. Decision 2 is a choice between two gambles. The expected payoffs are $110,000 for the first gamble, $500,000 for the second, and thus, the second is the logical choice. Here, subjects choose the second gamble, consistent with the numbers and rational self-interest, but that creates the complexity that the two decisions are inconsistent because the lower expected payoff is preferred in Decision 1 but the higher expected payoff is preferred in Decision 2—hence, the "paradox."

In the final task, pairs of subjects play a game of cooperation versus defection for rewards, which consists of a series of trials with a fixed payoff structure. At the start, subjects are given full information about the complete payoff structure, a typical example of which is shown at the bottom of Table 1. On Trial 1 and on alternate trials thereafter, a subject may stop the game and take the stated payoff or continue playing. In game theory, these payoff structures can be formalized as von Neumann–Morgenstern utilities (von Neumann & Morgenstern, 1947), and Rosenthal (1981) pointed out that with such utilities, the rational decision, which is an example of a Nash equilibrium, is the purely selfish one of never cooperating; that is, stop the game on Trial 1, take the payoff, and never cooperate. Players ought to be motivated to maximize their individual payoffs, and the average expected payoff is always lower for continuing than for stopping. In Table 1, a player's expected payoff is $1.5 on Trial 1, whereas it drops to $1 on Trial 2 if the player continues rather than stopping. The same is true on the other trials 3, 5, and 7. As in decision framing and the Allais paradox, adults do not follow the numbers or their rational self-interest. They normally continue playing for a few trials—the modal number of plays being 4 or 5 for payoff structures like those in Table 1.

Gist and Reasoning about Risk

In FTT, the verbatim-gist distinction is used to explain adults' irrational reasoning about risky choices, and that explanation predicts developmental reversals in which adolescents' reasoning is more rational than adults'. We saw that adults' reasoning does not follow the numbers or their rational self-interest. Note that this statement does take the verbatim-gist distinction into account because it only refers to the exact *verbatim form* of numbers (e.g., that 200 and one-third of 600 are the same number) and ignores any gist that subjects may extract from those numbers. It goes without saying that adults will extract such gist, because mining information meaning is a fundamental fact of cognition. Remarkably, this principle does not figure in traditional approaches to reasoning about risk, which assume that subjects somehow base reasoning on verbatim numerical values. According to FTT, this failure to incorporate the principle of gist extraction is crucial because gist is the crux of why adults' reasoning is illogical (e.g., Reyna, Estrada et al., 2011). Explicitly, adults not only extract a variety of gist representations as they process verbatim numerical inputs, but that gist is what reasoning normally relies on (for a review, see Reyna & Brainerd, 2011). The latter idea, which is called the fuzzy-processing preference (Brainerd & Reyna, 1990), reflects the fact that much research has shown that the gist of background information is more stable in memory and easier to process than its verbatim form and, hence, produces better reasoning overall. The fuzzy-processing preference is well established for a variety of tasks that involve reasoning about numerical information (Reyna & Brainerd, 1991a, 1993, 1994). Here is how it explains adults' decisions on the tasks in Table 1.

Taking framing first, a simple gist of option A is "some people live," and a corresponding the gist of option B is "some people live or none live" (Reyna & Brainerd, 1991b). Assuming that subjects value human life, the gist favors A, which is the option that adults in fact prefer. For the loss framer, a simple the gist of C is "some people die," and a corresponding the gist of D is "some people die or none die" (see Reyna & Brainerd, 1991b). Now, the gist favors the uncertain choice, which is the one that subjects prefer. The hypothesis that adults are reasoning on the basis of such gist has been confirmed in experiments in which the numbers in the paired options have been progressively stripped out, substituting the gist of the information (Betsch & Kraus, 1999; Kühberger, 1995; Kuhberger & Tanner, 2010; Mandel, 2001; Reyna & Brained, 1991b; Stocké, 1998). This pits the traditional view that reasoning is based on the actual numbers against FTT's view that it is based on the gist: Stripping out numbers and substituting gist must reduce framing preferences if the first view is correct, but it must increase them if the second view is correct. The data consistently show that framing preferences increase.

With this example in hand, readers can easily infer the gist that reasoning presumably relies on in the other two problems, but we spell it out for completeness. In the Allais paradox, to most of us $1 million and $5 million are both a great deal of money. Thus, the gist of the options in Decision 1 are A = "a large amount of money for sure" and B = "a large chance of a large amount of money and small chance of nothing." Seen in this way, who would not prefer the certainty of a great deal of money, even though the numbers say it conflicts with rational self-interest? The gist of the options in Decision 2 are C = "a small chance of a large amount of money and a large chance of nothing" D = "a small chance of a much larger amount of money and large chance of nothing." Again, the gist delivers a clear preference, which is now consistent with rational self-interest.

The controlling gist in the Centipede game is simpler yet. As subjects glance at the payoff structure at the bottom of Table 1 before the game begins, it is obvious that (a) much more money will be received if the game continues for a few trials than if it stops immediately and that (b) this will be equally obvious to any partner. After Trial 2, this is true regardless of the payoffs to individual subjects. For instance, suppose that a subject continued the game on Trials 1 and 3, and that the partner stops it on Trial 4. The partner receives a larger payoff

($12),but the subjects' payoff is larger than if the game had been stopped on Trial 1 ($4 vs. $1.5).

Developmental Reversals: Predictions and Data

We previously discussed age changes in storing and connecting gist. From that and what has just been said about gist processing preference in reasoning, how FTT predicts developmental reversals will already be evident. For adults to reason as FTT envisions in framing, the minimum conditions are that they extract bottom-line meanings such as "some people live," "some people die or no one dies," and so forth on the basis of the numbers. Similarly, the minimum conditions in the Allais paradox are that they extract bottom-line meanings such as "a large amount of money for sure," "a large chance of a large amount of money and small chance of nothing," and so forth. If these conditions are not met, reasoning will be more apt to rely on the verbatim content of numbers, and paradoxically, that will make it more logical according to standard theories. Those conditions are less likely to be met by adolescents than adults, which brings us back to the developmental literature on semantic processing capabilities.

Earlier, we stressed that such capabilities are more limited during childhood than at older age levels, according to simple indicators such as the categorization effect and spontaneous categorical clustering. The same literature shows that these basic semantic skills continue to develop throughout adolescence; that although they are more limited in children than in adolescents, they are more limited in adolescents than in young adults. Consider two examples: semantic interference and subjective organization. With respect to former, meaning content can impair performance on tasks that place a premium on remembering items verbatim, with proactive inhibition in recall being a classical example (e.g., Postman & Keppel, 1977). Subjects study and recall short words lists on which the words belong to the same taxonomic category—say, 8 lists of 10 different women's first names. Relative to a control condition with lists of unrelated word, recall of same-meaning items declines from list to list. Although such semantic interference is ubiquitous in adults, it is not usually detected in children until roughly age 13, after which it continues to wax throughout adolescence and early adulthood (Bjorklund & Hock, 1982). Concerning subjective organization, Tulving (e.g., 1983) observed that when lists of nominally unrelated words are studied and recalled, there will be idiosyncratic semantic relations among them for subjects who process meaning as intensely as adults do. Those idiosyncratic relations can be detected by measuring whether there is a statistically reliable tendency for nominally unrelated words to be clustered at adjacent output positions on consecutive recall tests. Adults display just such a tendency, and it seems to be good for memory because it is positively correlated with total recall. However, developmental data show that it is not detected until roughly the second half of the high school years and that its positive correlation with accuracy does emerge until sometime after that (Brainerd, Howe, & Desrochers, 1982). The continued unfolding of basic semantic processing during adolescence is how FTT explains that the types of false memories that are lower in childhood than in adolescence are also lower in adolescence that young adulthood (Reyna & Brainerd, 2011).

This continued unfolding forecasts adolescent-to-adult reversals in reasoning, too. If adolescents are less apt than adults to store and connect simple gists such as “furniture,” “animals,” and “cities” with lists of words, pictures, and sentences, they should also be less likely to store and connect gists such as “some people live” or “a large chance of a large amount of money and a small chance of nothing.” Therefore, their reasoning will be forced to rely more on the numbers themselves (or other verbatim information in tasks that do not involve numbers), which will favor decisions that are more logical and rational than adults’. There are several confirmations of such developmental reversals in the judgment and decision making literature, which actually date back to the early 1990s.

For decades, a major focus of that literature has been on illusions and biases in which judgments or decisions exemplify irrational reasoning. Illusions and biases have been studied with tasks like those in Table 1 and many others, with conjunction fallacies (Tversky & Kahneman, 1983), disjunction fallacies (Tversky & Koehler, 1994), and hindsight bias (Reyna, 2005) being influential cases in point. Although such phenomena have been studied primarily in adults, there is a growing developmental literature in which, surprisingly, classic illusions and biases increase with age. Jacobs and Potenza (1991) and Davidson (1991) were the first to report this pattern for base rate neglect, the representativeness heuristic, and noncompensatory reasoning strategies. However, they did not predict such findings and treated them as anomalous. Shortly thereafter, Reyna and Ellis (1994) predicted such effects for decision framing, based on FTT, with other developmental framing data having been more recently reported by Reyna and Farley (2006) and Reyna, Estrada et al. (2011). Other findings in the developmental reversal vein can be found in articles by De Neys and Vanderputte (2011) and Morsanyi and Handley (2008), and in still other articles that are reviewed in Reyna and Farley (2006). In all instances, although the fact that reasoning is more logical or rational among adolescents than young adults violates just about every theory of cognitive development, from Piaget to the present (e.g., Stanovich, West, & Toplak, 2011), the pattern is easily explained, indeed was predicted, on the ground that adolescents are less likely to process the gist that underlies adults’ biased reasoning. That leads adolescents to rely more on the actual verbatim information, which as we have seen supports reasoning that is less biased.

Beyond predicting developmental reversals, FTT's analysis of gist processing in adult illusions and biases has an important practical payoff: It provides a novel cognitive explanation of the classical phenomenon that we mentioned at the start of this section: the high incidence of risky decisions among adolescents. First, we should remind ourselves of some examples of those decisions: alcohol consumption, use of illegal drugs, smoking, reckless driving, and risky sexual behavior. Earlier, we noted that these activities have obvious rewards—for adults as well as adolescents, although adolescents may be more reward-sensitive. A key point that is often overlooked is that the *objective probability* of an undesirable outcome from any single example of any of these activities is invariably small (Reyna & Brainerd, 2011; Reyna & Farley, 2006). The chances of contracting a sexually transmitted disease that is not life-threatening or of pregnancy from unprotected sex with a new acquaintance are very small, and the chances of contracting HIV-AIDS are vanishingly small. Likewise, the chances of being arrested for any instance of alcohol consumption or drug use are small, as are chances of an accident or being ticketed for reckless driving, and no one ever contracted lung cancer from smoking a couple of cigarettes at a party. In short, when there is an opportunity to engage these activities, the objective situation is that the rewards are certain and the risk of an adverse outcome is small. The rational course, then, as an economist would say on the basis of utility theory, is to go ahead and take a risk.

The result is yet another surprising notion. Reasoning that is objectively more logical and rational, because it fits with actual verbatim information about risk and reward, is fundamentally less protective against unhealthy risk than gist-based, intuitive reasoning. The importance of this becomes apparent when one considers how the two types of reasoning differ for activities with catastrophic outcomes (see Reyna & Brainerd, 2011; Reyna & Farley, 2006). Returning to the example of unprotected sex, the rewards are certain, the chances of a catastrophic outcome such as HIV-AIDS are extremely low, and thus, the numbers say to have unprotected sex. In contrast, if the gist “HIV means slow painful death” is processed rather than the numbers, unprotected sex becomes too scary to contemplate. Returning to reckless driving, driving fast is exciting, even more so if a few friends are along for the ride, and the objective chances of an accident or of being stopped by the police are small. However, this, too, becomes too scary to contemplate if the gist “car crash means dead or maimed” is processed instead of the numbers. More extreme still, consider the decision of whether to play a single trial of Russian roulette for a very large payoff—say, $5 million—using a standard six-shooter. Following the usual rules of 1 loaded chamber and 5 empty ones, with the cylinder being spun to a random chamber, the reward is high-probability (87%), and the catastrophic outcome is low-probability (13%--actually, somewhat lower because guns can misfire). Thus, the numbers say that playing Russian roulette is quite rational, but it seems crazy if “hole in the head means dead” is processed instead (Reyna & Farley, 2006).

Summary

During adolescence, FTT makes further developmental reversal predictions about reasoning rather than memory. The predictions do not involve new theoretical principles. They grow out of the finding that the illusions and biases of adult reasoning, which have been extensively studied in judgment and decision making, are often caused by reasoning on the basis of the gist of information, rather than its verbatim content. Here, FTT research has identified simple gists that predict the form of biased reasoning on tasks such as decision framing, conjunction fallacies, disjunction fallacies, the Allais paradox, and others. That translates into developmental reversal predictions—with adolescents displaying reasoning that is more logical and less biased on tasks for which they are less apt to process the gists that dominate adult reasoning. That, in turn, generates a cognitive explanation of the high levels of risky behavioral that are characteristic of adolescence because the gists that adults process favor avoidance of even low-probability risks, particularly catastrophic ones.

Young Adulthood: the Dual-Recollection Hypothesis

Moving to the next developmental epoch, except for a few domains of psychology (e.g., clinical, comparative) the entire literatures of most fields (e.g., memory, perception, cognition, personality, and social psychology) are confined to experimentation with young adult subjects. We focus on some new predictions that FTT makes about a key episodic memory process, a retrieval operation called recollection, which, for the past three decades, has been intensively studied in young adults. We begin with a brief discussion of the tradition that currently motivates research on recollection—namely, dual-retrieval theories of recognition—and then consider FTT's conception of recollection.

Dual-Retrieval Theories of Recognition

Memory researchers date the origins of dual-retrieval theories of recognition to some findings of Strong (1913), who was interested in memory for advertising copy. In a curiously modern type of experiment, Strong's subjects studied a list of familiar words, and then responded to an old/new recognition test on which half the items were studied words and half were distractors. Following the test, the words they had recognized as old, regardless of whether they were actually old, were presented again, and the subjects introspected on the conscious experiences that had accompanied each word when they identified it as old. After sifting through subjects' introspective reports, Strong concluded that they fell into broad classes. In one, which is identified with a process called familiarity in dual-retrieval theories, subjects were confident that they had studied a word but they could not state any concrete reason ("had to be on the list," "just know it was there"). In the other type, which is identified with recollection in dual-retrieval theories, subjects referred to specific details that (a) had accompanied a word's presentation, and (b) they had become consciously aware of when the word appeared on the recognition test. Some details were objective (e.g., the visual appearance of a word, the visual appearance of the card on which it was printed) and others were subjective (e.g. thoughts, emotions, visual images, associations to other words). Crucially, Strong reported that the two phenomenologies were correlated with recognition accuracy: Recollective reports were mostly made for hits, whereas false alarms were predominately accompanied by familiarity reports. Beginning with Donaldson (1996), that same pattern has been noted in contemporary research, using more reliable measurement methods.

There was little interest in the recollection-familiarity distinction until the appearance of articles by Mandler (1980) and Atkinson (e.g., Atkinson & Juola, 1974), with the former being an especially powerful stimulus. Mandler showed that various findings about recognition be explained if it is controlled by independent recollection and familiarity operations, and he provided an everyday example of the difference between them (the butcher on the bus) that became a staple in textbooks. The definitions of these operations, in current theories (e.g., Rotello, Macmillan, & Reeder, 2004; Wixted & Mickes, 2010) as well as in Mandler's article, are as follows. Familiarity refers to circumstances in which subjects are confident that a test item is old, but they have no specific memory of its presentation—only the definite feeling that it was. Recollection, on other hand, refers to being consciously aware of a test item's presentation in a specific way—namely, being aware of *contextual details* that accompanied its presentation. To illustrate, suppose that the presentation of *hamburger* stimulates conscious awareness of the taste of mustard and of hunger pangs, and that the appearance of *hamburger* as a test item reinstates those earlier experiences and perhaps others as well (e.g., the font that it was printed in, where it appeared on the computer screen). In the words of others, recollection consists of "retrieving specific details associated with the prior presentation of an item" (Wixted, 2007, p. 152), "conscious recollection of any details about the experience" (Rotello et al., 2004, p. 589), and "conscious memory for contextual or episodic details of prior events" (Parks, Murray, Elfman, & Yonelinas, 2011, p. 862). The contextual details that are most commonly cited as examples are a miscellany of subjective information that subjects generate as they study items (emotions, inferences, associations to other words, visual and auditory images, and somatic responses), visual details when presentation is visual (font, color, size, position), auditory details when presentation is oral (voice gender, voice accent, pitch), and salient features of the laboratory room and apparatus. An important aspect of this definition of recollection, to which we shall return presently, is that it is not the prior presentation of *targets themselves* that subjects are remember but, rather, details that happened to *coincide* with their presentation.

The recollection-familiarity distinction and the content of the two retrieval operations are topics of ongoing theoretical and experimental work. Several measurement methods have been developed that separate the effects of recollection and familiarity—such as remember/know (R/K) judgments (Tulving, 1985), the process dissociation paradigm (Jacoby, 1991), and the dual-process receiver operating characteristic (Yonelinas, 1994). Theoretical ideas about the dynamics of the two have evolved, from an initial stage in which both were viewed as discrete processes, through an intermediate stage in which recollection was still viewed as a discrete process but familiarity was viewed as continuous, to the contemporary view that both are continuous processes. Along the way, immense behavioral and neuroscience literatures have accumulated (for reviews, see Brainerd, Gomes, & Moran, 2914; Diana, Reder, Arndt, & Park, 2006); Dunn, 2008; Heathcote, 2003; Malmberg, 2008; Migo, Mayes, & Montaldi, 2012); Rotello, et al., 2004); Yonelinas, 2002). Dual-retrieval theories have become staples of memory research, with the recollection-familiarity distinction being a core principle that is used to explain many important empirical effects (e.g., word frequency effects, levels of processing effects, divided attention effects, generation effects). There have been numerous attempts to isolate distinct brain regions for recollection and familiarity, with the current consensus being that medial temporal structures support both, that the hippocampus is particularly important for recollection, and that certain regions that are proximal to the hippocampus, such as the parahippocampal cortex, are particularly important for familiarity (Eichenbaum, 2005; Ranganath, 2010; but see Dennis, Bowman, & Vandekar, 2012).

FTT's Dual-Recollection Hypothesis

In dual-retrieval theories, recollection and familiarity are both univariate operations. However, Brainerd et al. (2014) pointed out that are reasons to think that recollection is actually bivariate, that FTT's verbatim-gist distinction is a major one, and that it should be possible to separate the two recollections using false-memory tasks. We mentioned that an interesting aspect of the definition of recollection is that it does not postulate conscious reinstatement of presented items *themselves*, only of details that accompanied those presentations. According to FTT's verbatim-gist distinction, however, subjects store verbatim traces of items per se and gist traces of their meanings, senses, and patterns. Contextual details like those in the conventional definition of recollection are stored in *both* *types of traces* because they are the episodic tags that allow the traces to be retrieved on memory tests. Under this conception, there are two distinct forms of recollection, target recollection and context recollection, which refer, respectively, to conscious reinstatement of item presentations per se and conscious reinstatement of contextual details that coincided with those presentations. Target recollection occurs when verbatim traces are retrieved and may or may not be accompanied by context recollection—depending on whether contextual details that are stored in verbatim traces also come to mind. Context recollection can occur when either verbatim or gist traces are retrieved, because both are episodically tagged, but gist traces should not produce target recollection. Finally, familiarity occurs when gist traces are retrieved but stored contextual details do not come to mind. Here, subjects will naturally feel confident that an item was presented because its meaning will seem familiar.

Although the two forms of recollection will often occur together, the memory literature contains clear examples of context-free target recollection and target-free context recollection. Free recall, for instance, provides straightforward illustrations of the former. When subjects start to recall a recently presented list, the subjective experience is that the first few items come vividly to mind individually, and we simply read them out of consciousness. Hence, target recollection is occurring, but subjects often fail to retrieve contextual details that accompanied the targets' presentations, a phenomenon that Shimamura and Squire (1987) called source amnesia. In the relevant experiments, subjects (a) study lists for which contextual cues (e.g., font, color, position, size) are systematically varied, (b) attempt to recall the lists, and (c) and finally respond to a recognition test for the contextual cues that were presented with each of the items that they were able to recall. The standard finding is that contextual details are not remembered for a substantial percentage of recalled items. For instance, using different designs, Mickes, Seale-Carlisle, and Wixted (2013) and Gomes and Brainerd (2015) found that contextual details could not be remembered for 37% of the items that had just been recalled. Shimamura and Squire pointed out that this same phenomenon is characteristic of patients with Korsakoff's syndrome.

Turning to target-free context recollection, the literature contains demonstrations in which subjects remember contextual details that accompanied presentations of specific items, but they cannot remember the items themselves. In the typical design (e.g., Ball, DeWitt, Knight,& Hicks, 2014; Cook, Marsh, & Hicks, 2006; Kurilla & Westerman, 2010), subjects study lists on which contextual cues that accompany targets are systematically varied. Next, they respond to old/new recognition tests or cued recall tests for those items, followed by recognition tests for details that accompanied *items that were not remembered*, as well as for items that were remembered. Obviously, target recollection is ruled out for items that were not remembered. Surprisingly from the perspective of traditional dual-retrieval theories, subjects are able to retrieve details such as font/color/size/position for items that cannot be remembered. Indeed, the ability to remember such details was uncorrelated with item memory in some experiments (Cook et al., 2006; Kurilla & Westerman, 2010), although the two were positively correlated in other experiments (Ball et al., 2014). False memory provides another important example of target-free context recollection. When subjects falsely remember items, target recollection should not occur because the items were not presented. However, when subjects falsely remember items that share meaning with presented ones (e.g., *car*, when *auto* was presented), they often report conscious awareness of contextual details that accompanied the presented items (Arndt, 2012; Payne, Elie, Blackwell, & Neuschatz, 1996).

Predictions About Recollection and False Memory

Brainerd et al. (2014) pointed out that target and context recollection are difficult to separate for items that were actually presented (true memory) because both support correct recognition/recall. However, they can be disentangled with false memory because they lead to opposite responses for items that were not presented. As noted, context recollection supports false memories: Being able to remember the voice in which an unpresented item was (not) pronounced or the font in which it was (not) printed supplies compelling subjective evidence for accepting it (Arndt, 2012). In contrast, when an unpresented item (*car*) prompts recollection of the corresponding presented item (*auto*), that is compelling subjective evidence for rejecting it. This latter phenomenon, recollection rejection, has been characterized as "a person ... may mistakenly recognize the word 'Dog' ... This error can be avoided, however, if one consciously recollects the study item at time of test (e.g., 'I know it wasn't "dog", it was "puppy".')" (Lampinen & Odegard, 2006, p. 652), and "the subject might have thought that both *table* and *chair* could have been in the study list. ... if they were able to clearly recall *table*, but *chair* was only vaguely familiar, then they might reason that *chair* probably was not studied. (Gallo, 2004, p. 121). Further, target recollection seems to be the only way to account for an ability that subjects are known to possess, which is the ability to firmly reject false items whose *surface form and meaning* are virtually the same as presented items, such as *auto* versus *autos* or *happen* versus *happened*.

The payoff is that the dual-recollection distinction generates predictions about the relation between recollection and false memory that are counterintuitive from the perspective of traditional theoretical ideas about that relation. Traditional ideas are rooted in a finding that was mentioned earlier; that recollection is predominantly associated with hits, while false alarms are dominated by familiarity. That suggests the widely-discussed hypothesis (see Brainerd & Reyna, 2005) that conditions that enhance recollection will reduce false memory for unpresented items. According to the dual-recollection hypothesis, however, whether or not false memory is reduced will depend on whether those conditions enhance target recollection or context recollection.

Most procedures for measuring recollection only distinguish between recollection and familiarity and do not separate the two forms of recollection, creating a paradoxical situation in which increased levels of recollection should sometimes suppress and sometimes enhance false memory. The most commonly used procedure, R/K judgments, is the prime example. R/K literature dwarfs those for all other separation techniques combined, consisting of over 1,000 published experiments. Subjects study a series of targets, normally words or pictures, respond to an old/new recognition test, and then make R/K judgments about items that were just recognized as old—with R responses being identified with recollection and K responses with familiarity. Instructions for making such judgments, which were developed by Rajaram (1993), are displayed in Table 2. Notice that R combines rather than separates the two recollections inasmuch as subjects are told to make such judgments (a) when a test item provokes “conscious recollection of its prior occurrence in the study list” (target recollection) *and when* (b) they become consciously aware of “aspects of the physical appearance of the word, or of something that happened in the room, or of what you were thinking and doing at the time ... a particular association, image, or something more personal from the time of study” (context recollection). Thus, when a manipulation elevates R judgments, it is unclear whether it does so because it elevates target recollection, context recollection, or both.

Owing to the sheer size of size of the R/K literature, there are manipulations that have been studied so many times that there is no doubt that they elevate R judgments, and under the traditional conception of the recollection-accuracy relation, they should also reduce false memory. Consistent with that view, many of them are known to suppress false memory. To illustrate, five manipulations that increase R judgments for presented items are replacing word lists with picture lists (Wagner, Gabrieli, & Verfaellie, 1997), increasing the number of times a list is presented (Dewhurst & Hitch, 1997), replacing longer lists with shorter ones (Rajaram, 1993), replacing lists of high-frequency words with lists of low-frequency words (Guttentag & Carroll, 1997), and testing young adult subjects rather than older adults (Duarte, Graham, & Henson, 2010). When these manipulations have been implemented in false memory experiments, each has lowered false memory (Brainerd, Payne, Wright, & Reyna, 2003; Goz, 2005; Gallo & Roediger, 2003; Schacter et al., 1999; Sugrue & Hayne, 2006).

However, the R/K literature contains many other manipulations that increase R judgments for presented items, such as generating rather than reading the items on study lists (Hicks, Marsh, Ritschel, 2002), studying lists under longer rather than shorter exposure times (Hirshman, Fisher, Henthorn, Arndt, & Passannante, 2002), studying items that are emotionally-valenced rather than neutral (Ochsner , 2000), studying items under full attention rather than divided attention (Mangels, Picton, & Craik, 2001), and studying items under deep rather than shallow encoding instructions (Lindsay & Kelley, 1996). When these particular manipulations are implemented in false memory experiments, the picture changes, and the data are consistent with the dual-recollection distinction. In each case, the manipulation *increases* false memory as it elevates R judgments for presented items (Abadie, Waroquier, & Terrier, 2013; Dewhurst, Bould, Knott, & Thorley, 2009; Howe, Candel, Otgaar, Malone, & Wimmer, 2010; Seamon, Luo, & Gallo, 1998; Toglia, Neuschatz, & Goodwin, 1999). In other experiments, in the source-monitoring literature (e.g., Ball et al., 2014), these manipulations have been found to improve memory for contextual details such as font/color/size/position—suggesting that, indeed, the reason they simultaneously increase R judgments and false memory is because they enhance context recollection.

FTT's dual-recollection principle explains some rather mystifying findings about recollection. We mentioned the classical finding (Strong, 2013), often reported in modern experiments (e.g., Conway, Collins, Gathercole, & Anderson, 1996; Rotello et al., 2004), that subjects rarely report recollective experience when they falsely accept distractors. It turns out that this pattern is not invariable. There are certain types of false memories for which subjects report high levels of recollective experience, using procedures such as R/K judgments (for a review see Arndt, 2012). Among them are the DRM illusion, Loftus (e.g., 1997) type memory suggestion, and false memory for narratives (e.g., Bransford, Barclay, & Franks, 1972). As strange as seems that false memories are accompanied by vivid phenomenological support, the finding is easily explained by the dual-recollection principle: Some types of false memories are very good at accessing contextual details that accompanied presented items. Direct evidence for that hypothesis can be found in recent experiments by Ball et al. (2014).

Finally, Brainerd, Gomes, and Moran (2014) noted that the dual-recollection principle makes several predictions about phenomena that, historically, have been of great interest to cognitive psychologists. Among them are: (a) The types of false memories that are most likely to trigger ersatz context recollection are semantic ones (Ball et al., 2014); (b) relations between recollection and familiarity will be different for target recollection than for context recollection (Moran & Goshen-Gottstein, in press); (c) target recollection supports (as well as suppresses) false memory in certain paradigms, notably memory suggestion and source monitoring (Brainerd, Gomes, & Nakamura, in press); (d) target recollection foments a memory version of the disjunction fallacy of judgment-and-decision-making research (Brainerd, Holliday, Nakamura,& Reyna, 2014); (e) context recollection foments a memory version of the conjunction fallacy of judgment-and-decision-making research (Brainerd, Holliday, et al., 2014); and (f) the often-reported finding that true memories are forgotten more rapidly than false ones (e.g., Lampinen, Copeland, & Neuschatz, 2001) is due to loss of the ability to use target recollection to suppress false memories.

Summary

Since the appearance of influential papers by Mandler (1980) and Atkinson (e.g., Atkinson & Juola, 1974), recollection has been the subject of vigorous theoretical development and experimentation. It is a central concept in dual-retrieval theories of episodic memory, and it is thought to be especially important in ensuring memory accuracy—both in the sense of correctly remembering presented items and suppressing false memory for unpresented items. Dual-retrieval theories treat recollection and familiarity as univariate processes, but FTT posits that recollection is actually bivariate. This dual-recollection principle makes the surprising prediction that conditions that increase the ability of presented items to retrieve recollective support can have opposite effects on false memory, depending on which type of recollection is elevated. R/K studies provide considerable support for that prediction. Of the many manipulations that are known to increase R judgments for presented items, some (e.g., studying picture lists or lists of low-frequency words) suppress false memory while others (e.g., studying lists under full attention or semantic orienting instructions) increase it. The dual-recollection principle makes several predictions about other important memory phenomena that are currently being studied.

Late Adulthood: Predicting Future Disease with Dual-Retrieval Processes

Now, we discuss predictions that the verbatim-gist distinction makes about memory declines during late adulthood and about late-life diseases, Alzheimer's dementia (AD) and mild cognitive impairment (MCI). It turns out that the verbatim-gist distinction specifies another retrieval process that is central to recall but is distinct from recollection and familiarity, reconstruction, which is crucial when it comes to parsing the processes that are responsible for late-life memory declines in healthy and impaired individuals because those declines are chiefly measured with recall tasks (e.g., Langa et al., 2005). First, we summarize FTT's account of recall, then we consider what it shows about the retrieval processes that underlie late-life memory declines, and finally, we show how it can be exploited to make progress on a key clinical goal: predicting future disease in older adults.

Dual-Retrieval Theory of Recall

Although dual-retrieval theories have been influential in the study of recognition, the modal view of recall is that it involves a single retrieval process, recollection (see Mickes et al., 2010). According to that view, only recollection is effective in recall because subjects must generate items their own. However, Brainerd, Reyna, and Howe (2009) observed that there is rich historical evidence that recall involves at least two distinct processes (see Brainerd et al., 1982), which consists of studies in which Markov models with three discrete performance states were fit the data of recall tasks (e.g., associative, cued, and free recall; Bower & Theios, 1964; Greeno, James, & DaPolito, 1971; Kintsch & Morris, 1965). In those models, there is an initial state U in which subjects have not learned enough about an item to be able to recall it at all, an intermediate state P in which they have learned enough to recall it with some average probability $0 < p < 1$, and a terminal state L in which recall is errorless.

Brainerd et al. (2009) applied the verbatim-gist distinction to those findings and proposed the following account of recall of a series of study-test cycles. Subjects store verbatim and gist traces of list items, as always, and learn to recall them via a recollective retrieval operation that processes the former and a nonrecollective one that processes the latter. The recollective operation, *direct access*, retrieves verbatim traces items without searching through traces of other Items. It is the faster operation, and it produces errorless recall: When an item's verbatim trace is retrieved, its surface from is consciously reinstated, so that subjects can simply read it out of consciousness, much as actors speak lines as they are whispered by a prompter or shown.

Despite the speed and accuracy of direct access, it has a crucial limitation. We mentioned that verbatim traces are sensitive to the interference that accumulates during a memory test (Brainerd & Reyna, 1993), so they become harder to access as the test proceeds and direct access degrades (Barnhardt, Choi, Gerkens, & Smith, 2006; Payne et al., 1996). If learning becomes so advanced that verbatim traces remain accessible in the face of mounting interference, subjects may rely exclusively on direct access, but that does not happen in most recall experiments. Instead, in order to continue recalling items, the reconstruction operation is activated as direct access begins to fail.

Reconstruction avoids the interference obstacle by processing gist traces in order to *regenerate* items. In addition to being less sensitive to interference, gist traces are not representations of items' full surface forms but, rather, only of partial-identifying information—especially semantic information such as "animal" and "pet" for *dog*, "furniture" and "home" for *couch*, or "cola" and "soft drink" for *Pepsi*. Research on phenomena such as feeling-of-knowing and tip-of-the-tongue shows that subjects retrieve traces of partial-identifying information on recall tests and use them to regenerate individual items (see Brown & McNeill, 1966; Hicks & Marsh, 2002; Koriat, 1993, 1995; Koriat, Levy-Sadot, Edry, & de Marcas, 2003). In one conception, reconstruction uses partial-identifying information to generate sets of candidate items that match that information; for instance, *cat*, *dog*, and *parakeet* for “pet.” As recall tests operate under time constraints, these sets have to be small enough to be processed within those constraints. An important feature of these sets is that they will contain false candidates (*cat*, *parakeet*) as well as true ones (*dog*) and sometimes only false ones because, of course, gist traces are only fuzzy matches.

Thus, reconstruction is error prone, and indeed, intrusions could swamp correct recall if subjects merely output all the candidates in search sets. To avoid that catastrophic result, a slave judgment operation performs confidence checks before releasing candidates for output. In contrast to the notion that familiarity is not useful in recall, it is the familiarity operation that is assumed to execute those confidence checks: Reconstructed candidates, like recognition probes, generate familiarity signals that are processed by the judgment operation. Subjects set a decision criterion along an axis of familiarity strength and release candidates for recall when they exceed it. Finally, we described reconstruction as a nonrecollective process, by which we meant that it is not a *necessary* concomitant of reconstruction. Actually, gist traces, like verbatim traces, store contextual details, and therefore, subjects may sometimes experience context recollection during the course of reconstruction.

Summing up, the two retrieval operations have advantages and disadvantages. Direct access is errorless recall, but verbatim traces become inaccessible as interference mounts, unless learning has reached an advanced state. Reconstruction is that it is far less susceptible to this problem, but it is error prone because gist traces will generate false as well as true items, and false ones will sometimes pass the familiarity check and be recalled. Thus, the advantage of direct access is the disadvantage of reconstruction, and conversely, so that to some degree, they work together to improve recall by compensating for each other's weaknesses.

Direct access, reconstruction, and familiarity judgment can all be measured in recall experiments using Markov models that are composed of the aforementioned states (U, P, and L). The particular models that we have used distinct parameters that measure each of these retrieval operations, which are defined in Table 3, where it can be seen that each operation is measured by a pair of parameters. One parameter of each pair measures the corresponding process early in learning (D_1, R_1, J_1), and the other parameter in each pair measures the same process later on in learning (D_2, R_2, J_2). Brainerd et al. (2009) showed that all of these parameters can be estimated with any conventional recall task, as long as it involves three or more study-test cycles. Because even young children and older adults with dementia can perform such tasks, all of the retrieval operations can be measured in subjects with rather pronounced cognitive limitations.

Parsing Memory Declines in Older Adults

We have a corpus of data sets available in which older (mean age = 70-80) and younger adults performed associative, cued, and free recall tasks that meet the conditions that were just described for estimating the parameters in Table 3 (see Brainerd et al., 2009). The data come from experiments involving several hundred subjects that were published over a period of two decades. Naturally, age declines in recall were a core pattern, but by retrospectively estimating parameters that measure the three retrieval processes, we can now pinpoint the reasons for that decline. What should be found?

As background, there is a literature in which dual-retrieval models of *recognition* have been used to separate the contributions of recollection and familiarity to age declines, using procedures such as R/K, the process dissociation paradigm, and dual-process ROC analysis. Two consistent findings have been that (a) declines in recollection are substantial between the 20s and the 70s but (b) declines in familiarity are small and, as a general rule, not statistically reliable (e.g., Anderson et al., 2008; Parks, 2007; Skinner & Fernandes, 2008; Toth & Parks, 2006). Because the dual-retrieval model assumes that the *J* parameters in Table 3 measure familiarity, an obvious prediction is that those parameters should exhibit little or no age decline. That is not a trivial prediction, considering that recall is different than recognition and, importantly, is far more difficult for older adults. What about direct access and reconstruction? Finding a does not supply definite predictions about direct access because, as we saw, dual-retrieval models do not separate target recollection from context recollection, and therefore, it is therefore unclear whether age declines in recollection on *recognition* tasks are due to one, the other, or both. However, aging data from other types of tasks that are slanted toward target recollection, such as older adults' reduced ability to suppress false memories (e.g., Budson et al., 2006), suggest substantial declines in target recollection and, hence, in the *D* parameters of Table 3.

Turning to reconstruction, less is known about aging trends in this retrieval operation because it falls outside the scope of traditional dual-retrieval methodologies. Thus, it is necessary to rely primarily on indirect evidence, which is not entirely consistent. On the one hand, findings from a variety of semantically-oriented tasks show that the ability to store gist traces of study items is largely spared during aging (Reyna & Brainerd, 2011; Spaan, Raaijmakers, & Jonker, 2003). This argues for little or no age decline in the *R* parameters of Table 3. On other hand, using reconstruction to search memory for candidate items that match gist traces and then using familiarity to winnow them are effortful processes that presumably require executive control. There is extensive evidence from other tasks that such processes decline during aging (e.g., Clark, Schiehser, Weissberger, Slamon, Delis, & Bondi, 2012). The indicated prediction, then, is that the *R* parameters should decline, but not as markedly as the *D* parameters.

To generate overall age patterns for direct access, reconstruction, and familiarity judgment, we estimated the parameters in Table 3 for each of the data sets in our corpus and then averaged the estimates over data sets. The results are displayed in Figure 3, when these processes are measured at the start of a recall experiment (Panel A) and when they are measured later on (Panel B). There are five global patterns, which are consistent with theoretical predictions but also go beyond those predictions in instructive ways. First, there was no evidence of age declines in familiarity judgment, regardless of whether it was measured at the start of learning or later on. The estimated values of the *J* parameters were high and suggest that, overall, subjects released roughly 80% of their reconstructions for output. Further, because intrusion rates were low in the experiments in our corpus (< 5%), the indication is that the search sets that subjects generated contained many more studied than unstudied items. Second, the direct access parameter declined markedly with age (from .50 to .17), but that decline was concentrated within learning that occurred after Trial 1. This parameter's values were comparable for younger and older adults on Trial 1 (.31 vs. .28), but not later on.

The third finding in Figure 3 is that the reconstruction parameter also declined with age (from .49 to .24), but this decline was also concentrated within post-Trial 1 learning. *R*'s values were comparable for younger and older adults on Trial 1 (.38 vs. .35), but not later on. Further, as expected, a visual inspection of the age declines in Panel B shows that the declines for direct access were roughly twice as large as those for reconstruction. Fourth, a visual comparison of the values of the *D* parameter in Panel A versus Panel B reveals that the reason that age declines are concentrated within later learning is that there is an Age X Trial reversal in the difficulty of direct access. Specifically, direct access becomes *easier* for young adults as trials unfold (*D* increases from .31 to .50), but it becomes *harder* for older adults (*D* drops from .28 to .17). Fifth, a visual comparison of the values of the *R* in Panel A versus Panel B reveals a parallel Age X Trial reversal in difficulty: Reconstruction becomes easier for young adults as trials unfold (*R* increases from .38 to .49), but it becomes harder for older adults (*R* drops from .35 to .25).

Thus, on the one hand, the global trends in direct access, reconstruction, and familiarity judgment are in accord with theoretical prediction. Familiarity judgment is completely spared, direct access and reconstruction both decline, and the declines in direct access are more pronounced. On other hand, the declines in direct access and reconstruction are due an Age X Trial cross-over in the difficulty of learning to retrieve in a recall experiment. It becomes easier for younger adults but harder for older adults. There are various hypotheses about the reasons for this cross-over that have not yet been tested. However, one can say that the explanation is not likely to lie in processes that are specific to target recollection (*D* parameters) or to using partial-identifying information to generate recall candidates (*R* parameters). That is because both processes exhibit the cross-over, and further, the magnitude of the cross-over is comparable for the two types of retrieval. Thus, processes that have very general effects on learning difficulty seem like the place to begin the search for explanations.

Predicting Future Impairment and Dementia

Last, we turn attention to a major clinical phenomenon in aging, which is the marked declines in episodic memory that are associated with AD and its antecedent, MCI. More than two-thirds of dementia diagnoses after age 70 are AD diagnoses, making it by far most common form of dementia after age 70 (e.g., Plassman et al., 2007). In the U.S., roughly 20% of people who live beyond age 75 will convert to AD (Hebert, Scherr, Bienias, Bennett, & Evans, 2003), which is usually preceded by MCI—a less severe condition. The key thing that unites AD and MCI is that both are fundamentally diseases of episodic memory, by which we mean that impairments in episodic memory are their diagnostic hallmarks. For instance, the diagnostic criteria for AD in the *DSM-5* (American Psychiatric Association,

2013) specify (a) clinically significant impairments in episodic memory and (b) clinically significant impairments in at least one of four other domains (executive function, language, motor function, or object identification). Thus, individuals who do not show episodic memory impairment cannot be diagnosed with AD, which leads to the question of what is meant, clinically, by “episodic memory” and by “significant impairment.” The definition of the former is just what a memory researcher would mean—namely, performance on recall and recognition tests, especially recall tests because they are more sensitive to memory declines than recognition. To provide objective measurements, the batteries of neuropsychological tests that are used to diagnose AD include clinical recall instruments, with the Consortium to Establish a Registry for Alzheimer's Disease (CERAD) recall test (Morris et al., 1989) and the Rey Auditory Verbal Learning Test (RAVLT; Rey, 1941) being among the most widely used. Both are standard laboratory free recall tests, in which subjects receive a series of study-test cycles (3-5) on a short supraspan list (10-15 words), and performance on such tests is known to be the best single marker of AD in older adults (de Jager, Hogervorst, Combrinck, & Budge, 2003) . To say that individuals display “significant impairment” on such tests means two things. First, their performance must be far below the performance norms for healthy age-mates, and second, it must represent a decline from earlier levels of recall. (The second requirement excludes individuals who have always performed poorly on memory tests.) A final stipulation for the diagnosis of AD is that declines cannot caused by other diseases—such as epilepsy, cardiovascular disease, diabetes, Parkinson's, or stroke—that also impair episodic memory.

Turning to MCI, the diagnostic criteria are the same as for AD diagnosis, except for the first one, which specifies that there must be impairment in episodic memory and in at least one other domain. For an MCI diagnosis, significant impairment in either episodic memory (called amnestic MCI; a-MCI) *or* in any one of the other four domains (called non-amnestic MCI; n-MCI) suffices (Peterson, 2004). (Significant is defined as at least 1.5 *SD*s below the performance of healthy age-mates.) Unlike AD, then, memory impairment is not required for MCI. Actually, however, it is the modal reason for MCI diagnoses because roughly two-thirds of them are a-MCI (Petersen et al., 2010), so that performance on recall tests such as the CERAD and the RVALT is also the best single marker of MCI (e.g., Harel et al., 2011). a-MCI is a precursor of AD but n-MCI is not, so that the standard disease progression in older adults is from healthy to a-MCI to AD (see Brainerd et al., 2013).

The memory impairments that are measured by the CERAD, RAVLT, and similar instruments are merely test scores that tell us nothing about which underlying processes are responsible for those impairments. The obvious theoretical questions are: What are those processes, and are they the same for MCI and for AD? Without answers to such questions, we lack a theoretical characterization of these diseases. Theoretical characterization is clinically important because it points the way to factors that might predict future MCI in healthy individuals and future AD in MCI patients (Brainerd et al., 2014). It also points the way toward effective treatment by revealing probable disease mechanisms (Brainerd et al., 2009). Not surprisingly, there has been work on these questions that implemented recognition-based dual-retrieval distinctions, work that was motivated by the fact that some of the brain areas that have been foci of dual-retrieval research with young adults are regions that exhibit pathology in MCI and AD (Nelson, Braak, & Markesbery, 2009).

The predominant hypothesis to emerge from this work is a recollection-deficit hypothesis about AD; that AD memory impairment consists of marked deficits in recollection but sparing of familiarity (see Bugaiska, Morson, Moulin, & Souchay, 2011; Reyna & Brainerd, 2011). There has been far less dual-retrieval work on MCI, but recently, some investigators have proposed a similar hypothesis that memory impairment in MCI also consists of deficits in recollection, but less severe ones, coupled with sparing of familiarity (Serra et al., 2010; Westerberg et al., 2006). As mentioned, there are many published studies in which traditional recognition-based methods of measuring recollection and familiar have been applied to normal aging, with the result that aging declines are usually found to be dominated by declines in recollection. Thus, the recollection-deficit hypothesis is just an extension to disease of the modal pattern in healthy aging.

A contrasting hypothesis has been proposed in FTT, according to which the memory declines in disease are different than those in healthy aging (Brainerd et al., 2009; Reyna & Brainerd, 2011). FTT's hypothesis is motivated by the finding that declines in traditional measures of recollection are very extensive well before healthy adults reach age 70. It is only *after that age* that conversions to MCI and AD become frequent, which seems odd if recollective declines are responsible for memory impairment in those diseases. Moreover, the cumulative declines before age 70 are so large that the additional ones that would be necessary to meet the diagnostic criterion for a-MCI would put recollection at near-floor. That effectively rules it out as the cause of the further declines that occur in transitions to AD. This would leave nonrecollective retrieval processes as more likely sources of AD memory impairments, and importantly, we saw that one of them, reconstruction, falls outside the scope of conventional dual-retrieval methodologies.

Pitting FTT's alternative hypothesis against the traditional one requires measurements of recollection, reconstruction, and familiarity in well-characterized samples of older adults with MCI and AD diagnoses and healthy control subjects of the same age. It turns out that those measurements are quite easy to obtain with neuropsychological batteries that are used to diagnose these conditions (e.g., Langa et al., 2005) because, as noted, their recall tests are the same laboratory tasks the meet the specifications of the dual-retrieval model. Consequently, the direct access, reconstruction, and familiarity judgment parameters in Table 3 can be estimated for the clinical performance of patient populations just as readily as they can be estimated for the laboratory performance of other subject samples (Brainerd et al., 2014). In order to pinpoint the retrieval processes that are associated with memory impairment in MCI and AD, we relied on a national data set that contains neuropsychological test scores for large samples of healthy, MCI, and AD individuals. This data set comes from the Aging, Demographics, and Memory Study (ADAMS) of the National Institute on Aging's Health and Retirement Study (HRS; Health and Retirement Study, 2011). A major advantage of the ADAMS is that it is the only nationally representative sample of healthy, MCI, and AD individuals, which means that findings for the ADAMS diagnostic groups should generalize broadly to older adults in the U.S.

ADAMS subjects are a nationally representative sample of 856 individuals (mean age = 81.6, range = 70-110) from the larger HRS pool (Langa et al., 2005). These subjects received neuropsychological testing and were diagnosed for the presence of neurocognitive impairment. They participated in one to four separate waves (A, B, C, and D) of testing and diagnosis over six years. During Wave A, all of them completed a 3–4 hour neuropsychological assessment, medical examinations, and extraction of tissue samples for genotyping. The neuropsychological assessment was used to classify subjects, with 304 being classified as healthy (mean age = 78), 98 being classified as MCI (mean age = 83.2), 224 being classified as AD (mean age = 84.5), and the remaining subjects being assigned other classifications (see Brainerd et al., 2011).

As part of their Wave A assessment, all of these subjects received the CERAD recall test, which consists of three study-test free recall cycles on a 10-word list, followed by a delayed recall test after a 5 min filled interval. Our focus was on the CERAD data, which were input to the dual-retrieval model to estimate the parameters in Table 3. First, however, we conducted tests of model fit. Although it is well known that models of this sort fit the data of young adults and healthy older adults (Brainerd et al., 2009), there are no comparable findings for MCI and AD patients. However, when the model was fit to the ADAMS CERAD data, it fit the data of the MCI and AD groups just as well as it fit the data of the healthy subjects.

It is possible to estimate the parameters in Table 3 in two ways for CERAD data. First, they can be estimated as learning parameters, which is how they are defined in Table 3, so that increasingly larger values of *D, R*, and *J* mean that it is increasingly easier to learn how to directly access, reconstruct, and make familiarity judgments about list items. Second, the amount of change (forgetting) in these parameters between the last study-test cycle and the 5 min delayed test can be estimated. Now, increasingly larger values of *D, R,* and *J* mean that it is increasingly harder to retain what was learned about direct access, reconstruction, and familiarity judgment.

The first question that we asked about these data was simply: Which retrieval processes differentiated the groups of older adults who were classified as healthy, MCI, and AD? The answer, which is shown in Figure 4, is that only a single retrieval process, reconstruction, did. On the one hand, mean estimates of the *J* parameters were very similar for the healthy, MCI, and AD groups and in the neighborhood of .60. Obviously, that is consistent with the previously reported finding that familiarity judgment is largely spared in normal aging. In addition, mean estimates of the *D* parameters were very similar for the healthy, MCI, and AD groups and in the neighborhood of .05. That seems inconsistent with the previously reported finding that direct access declines in normal aging. However, note that mean value of the *D* parameters is much lower than it was earlier (cf. Figure 3). That is because the earlier data were for older adults who, like their younger adult comparison groups, were highly educated, whereas the ADAMS older adults are nationally representative. Thus, the ADAMS data provide a statistically more accurate picture.

Although direct access and familiarity judgment did not differentiate the groups, it is clear from Figure 4 that reconstruction did. For instance, estimates of *R* during learning for healthy older adults were roughly 50% larger than the corresponding estimates for the MCI group and roughly three times larger than the corresponding estimates for the AD group. Forgetting how to reconstruct items was also tied to diagnostic group. First, it can be seen that reconstructive forgetting was at-floor; if healthy subjects learned how to reconstruct a list item, they did not forget how to reconstruct it over the delay. Second, in contrast, reconstructive forgetting was quite noticeable in impaired subjects, even though the delay was only 5 min. If MCI subjects learned how to reconstruct an item, they would forget how to reconstruct it roughly half the time, and if AD subjects learned how to reconstruct and item, they would forget how to reconstruct it roughly three-quarters of the time.

Thus, application of the dual-retrieval model to clinical recall data yielded a very precise characterization of the reasons for the differences in memory performance between healthy, MCI, and AD groups. This brings us to important question of whether it is also possible to predict future disease transitions with these processes, which is not the same thing. Merely because a specific retrieval process, reconstruction in this instance, differentiates existing diagnostic groups from each other does not mean either (a) that current variation in that process within a group (say, healthy subjects) will predict which subjects are likely to transition to other groups (say, MCI or AD) at some later date or (b) that current variation in processes that do not differentiate existing groups cannot predict such future transitions. Such predictions are quite important clinically, as older adults sometimes seek medical advice about the likelihood that they will become demented during their lifetime.

Most often, genetic tests are used for that purpose. The ε4 allele of the *APOE* is by far the best genetic marker of AD diagnoses. It has long been known that roughly half of older adults with such diagnoses are either heterozygous or homozygous for this allele (Corder et al., 1993; Strittmatter et al., 1993). Consequently, tests for its presence are sometimes used to advise older adults about whether they are at increased risk of AD, but does the presence of ε4 actually *predict* of future disease? We recently reported some cautionary findings (Brainerd et al., 2013). As mentioned, ADAMS subjects were genotyped for the presence of ε4 during Wave A, and as also mentioned, many of them participated in multiple waves of subsequent testing. They were reclassified following each wave so that over time, someone who began with a healthy classification could remain there or transition to an MCI classification, and someone who began with an MCI classification could remain there or transition to an AD classification. Thus, it is possible to determine whether, in this nationally representative sample, the presence of ε4 in subjects who are currently healthy predicts future MCI and whether its presence in subjects who are currently MCI predicts future AD. The results are displayed in Figure 5. There are two findings. First, consider the bars for healthy subjects who remain healthy throughout the study (H → H) versus healthy subjects who transition to MCI at some point (H → MCI). It is clear that ε4 predicts that transition because the percentage of ε4 carriers is approximately 20% in the H → H group and approximately 50% in the H → MCI group. Second, consider the bars for MCI subjects who remain MCI throughout the study (MCI → MCI) versus subjects who transition to AD at some point (MCI → AD). Here, it is apparent that ε4 does not predict that transition because the percentage of ε4 carriers is approximately 45% in both groups. The latter lack of prediction is quite significant clinically because older adults typically do not seek advice about future dementia until after they have been diagnosed with some weaker form of impairment (Brainerd et al., 2013).

It turns out that the retrieval processes in Table 3 fare considerably better than ε4 when it comes to predicting future disease. Here, we conducted an analysis that was similar to the one that was just described, except that the data consisted of estimates of retrieval parameters rather than presence-absence of ε4. The results appear in Figure 6. As can be seen in Panel A, the same process that initially differentiated all diagnostic groups, reconstruction, also predicted which MCI subjects were at increased risk of transitioning to AD (which ε4 did not predict). Across the three study-test cycles of the CERAD, the average value of *R* was nearly 50% higher for subjects who remained MCI throughout the study than for MCI subjects who transitioned to AD. The results for H → MCI transitions were different, as can be seen in Panel B. Although retrieval processes still predicted future disease, it was not reconstruction that predicted; rather, it was direct access. Specifically, healthy subjects who subsequently transitioned to MCI were much more likely (more than twice as likely) to forget how to directly access list items during the 5 min delay that subjects who remained healthy. Another interesting result appears at the far right of Panel B. During the course of the ADAMS, a few subjects who were initially healthy eventually transitioned all the way to AD. The number was far too small for reliable analysis of the ε4 data, which are binary (present-absent), but it was adequate for reliable analysis of parameter values, which are probabilities. As can be seen in Panel B, familiarity judgment during initial learning and forgetting how to directly access items both predicted which subjects in the healthy group would eventually receive AD diagnoses.

Summary

One of the newest applications of FTT's verbatim-gist distinction is to memory declines in healthy aging and in transitions to diseases such as MCI and AD. The distinction supplies the basis for a theory of recall that goes beyond the current view that recall is purely recollective. It also adds a new process, reconstruction, to the recollection and familiarity processes of dual-retrieval models of recognition. The resulting theory posits that recall is supported by two basic forms of retrieval—direct access of verbatim traces, which is a target recollection operation, and reconstruction from gist, which is accompanied by a “slave” judgment operation that assess the familiarity of reconstructions.

All of these processes can be simultaneously measured with recall data, using a simple Markov model. Applications of that model to healthy aging show that declines in direct access retrieval—and to a lesser extent, declines in reconstructive retrieval—are at heart of the reductions in recall that are observed between early and late adulthood. Applications to neurocognitive impairment in older adults show that subjects who are currently healthy differ from those who are currently MCI or AD in their ability to learn how to reconstruct list items and to preserve that learning. In addition, these applications show that measurements of direct access, reconstruction, and familiarity judgment can predict future AD in older adults with MCI diagnoses and can predict future MCI and future AD in older adults who are currently healthy.

Afterword

FTT is most commonly employed as a theory of adult episodic memory and of adult judgment-and-decision-making, but it is also a theory of cognitive development, both in origin and content. Our aim in this article has been to give flesh to that fact by discussing predictions that FTT makes about four major epochs of cognitive development and by summarizing published findings on those predictions. To establish that FTT is a contemporary approach to cognitive development, we have emphasized research programs that are either recent (developmental reversals in false memory and in reasoning) or very recent (bivariate recollection and late-life memory impairment). During childhood, FTT makes counterintuitive predictions about a topic that first became prominent in criminal cases that involved the memories of child witnesses. For more than a century, it has been widely supposed that childhood is an era when false memories are at peak levels and that there are broad-based declines between childhood and adolescence. However, FTT predicts that semantic false memories, which are the most common variety in the courtroom and everyday life, can sometimes be lower during childhood than later on, and it specifies the conditions under which those developmental reversals should be observed. Such predictions have been confirmed in dozens of contemporary studies. Turning to adolescence, FTT makes further counterintuitive predictions about the risky behavior that is prototypical of this age range and about declines in risky behavior between adolescence and young adulthood. The standard explanation assumes that the causes are socio-emotional immaturity rather than cognitive immaturity because cognitive development is largely complete by adolescence. However, FTT posits that cognitive immaturity, in the form of reliance on representations that capture the verbatim form rather than the gist of risky situations (e.g., illegal drinking, unprotected sex or reckless driving), is a major cause. Consistent with that prediction, many studies have found that adult behavior is guided by simple gists that avoid risk but adolescents' behavior is not. Counterintuitively, the reasoning that adolescents deploy involves a more logical, rational exploration of verbatim facts than the streamlined, gist-driven reasoning that adults deploy.

Turning to young and late adulthood, the predictions that we focused on have been targets of research during the past year or two. In young adulthood, we examined predictions about retrieval that run counter to a conception that has been preeminent for more than three decades. According to that conception, episodic memories are recovered via a recollection operation that reinstates realistic contextual details (sights, sounds, smells, feelings) that accompanied an event's prior occurrence and via a familiarity operation that is devoid of such details. According to FTT, however, there are two distinct recollection operations—the classical variety plus a target variety. The two recollections are memory analogues of the figure-ground and part-whole distinctions of perception, and they have different consequences for episodic memories that are true versus false: Context recollection supports both, whereas target recollection simultaneously supports true memories and suppresses false ones. The results of false memory studies show that, indeed, these distortions are driven in opposite directions by context recollection and target recollection.

With respect to late adulthood, memory declines are hallmarks of that epoch, much as risky behaviors are hallmarks of adolescence. Moreover, the most common forms of late-life cognitive impairment, AD and MCI, are quintessentially diseases of memory inasmuch as clinically significant deterioration of episodic memory is required for an AD diagnosis, and it also the basis for roughly two-thirds of MCI diagnoses. The dominant explanation is a continuity hypothesis, so-called because it stresses similarities between what underlies the deterioration and what underlies memory declines during healthy aging—namely, declines in recollective retrieval. Although there is evidence favoring such an explanation of memory declines during healthy aging, FTT posits another retrieval operation, reconstruction from gist, that is not usually measured in aging research, which may be prominent in transitions to MCI and AD. Support for the importance of reconstructive retrieval emerged when techniques for separating it from recollection and familiarity were applied to a nationally representative sample of heathy, MCI, and AD subjects. In particular, reconstruction was the key retrieval process that differentiated these groups, and over time, it was the retrieval process that predicted which MCI patients were at increased risk of converting to AD over time.

In all of the epochs that we have featured, FTT's predictions fall out of its core distinction between verbatim and gist representations: Developmental reversals in false memory and in reasoning follow from limitations in children's and adolescents' abilities to store the bottom-line meaning of experience; the bivariate nature of recollection follows from the fact that retrieval of verbatim traces produces mental reinstatement of targets per se, whereas retrieval of gist traces produces mental reinstatement of contextual details; and the importance of declines in gist-based reconstruction in AD and MCI follows from the substantial declines in verbatim retrieval that have already occurred during healthy aging. This method of theorizing, in which as many explanations and predictions as possible are wrung out of the same set of principles, is more reminiscent of Piaget than of most contemporary theoretical work. Contemporary work, as is well known, tends to be domain-specific, with theoretical principles being carefully trained on delimited phenomena (e.g., the growth of numerical reasoning, false beliefs, or spatial judgments). In contrast, Piaget, with his stages and structures, sought to connect development in spheres as diverse as memory, mathematical and scientific reasoning, spatial reasoning, logic, and perception with a single set of ideas. In FTT, the use of the verbatim-gist distinction to predict new effects in spheres as diverse as risk-taking, false memory, and cognitive impairment in neurological diseases has the same goal. So far, as we have illustrated here, the attempt has led to a number of productive lines of research that would not otherwise have been undertaken.

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Highlights

- Lifespan implementation of fuzzy-trace theory's verbatim-gist distinction.
- Verbatim-gist distinction predicts developmental reversals.
- Verbatim-gist distinction predicts two forms of recollection.
- Verbatim-gist distinction explains memory loss in dementia.

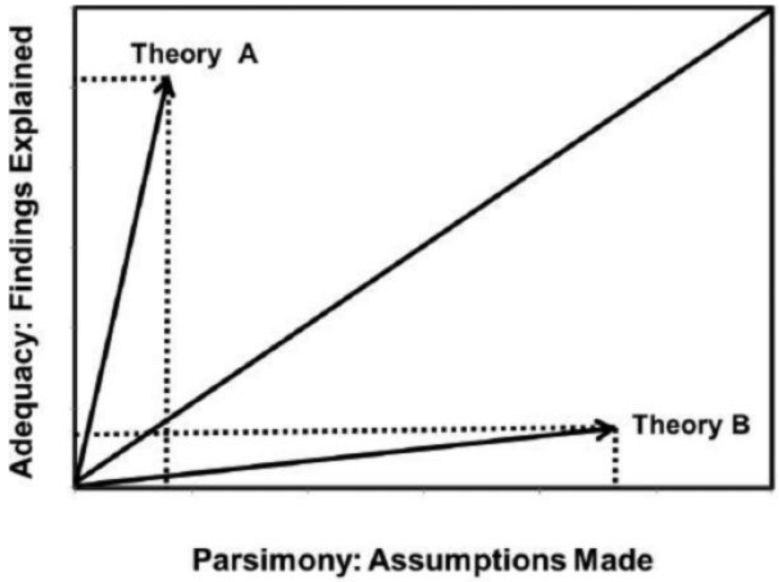

Figure 1.

Vector space representing the trade-off between explanatory adequacy and explanatory parsimony. Theories are vectors in this space, with those that fall above the diagonal being more successful that those that fall below because they explain more findings with fewer assumptions.

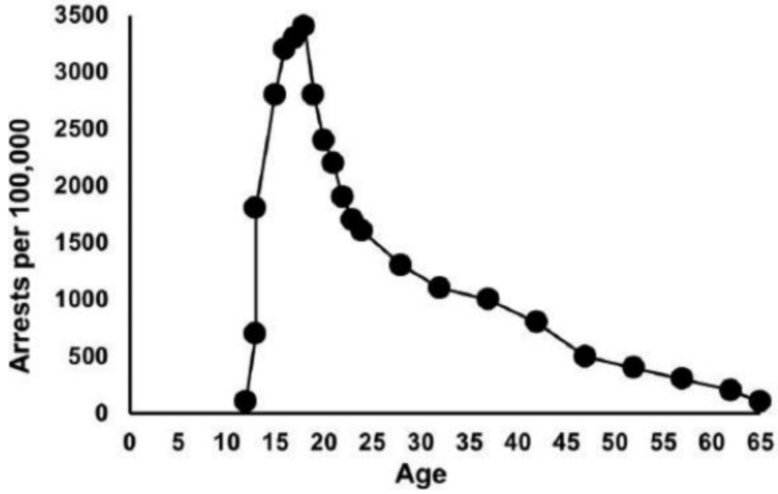

Figure 2.
Arrests for serious crimes in the U.S. as a function of age.

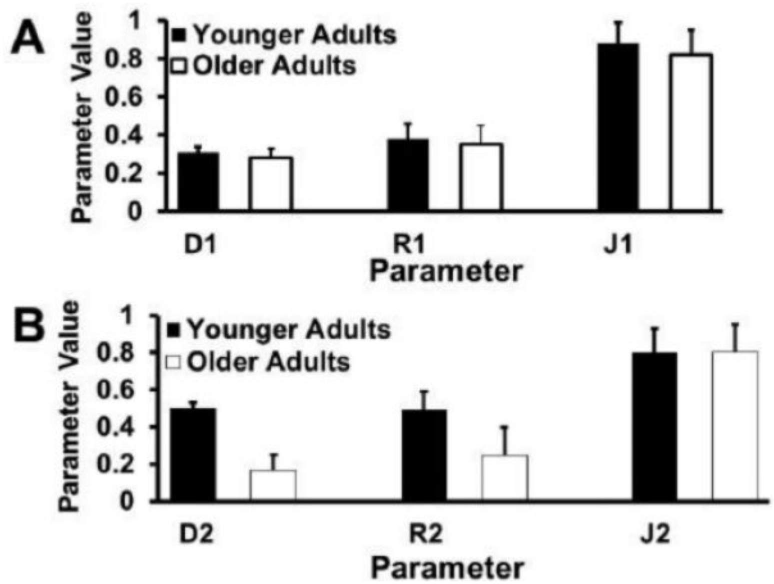

Figure 3.
Developmental trends in three retrieval underlying retrieval processes in recall. In Panel A, D_1, R_1, and J_1 are the probabilities of successful direct access, reconstruction, and familiarity judgment, respectively, on the first study-test cycle of a recall experiment. In Panel B, D_2, R_2, and J_2 are the probabilities of successful direct access, reconstruction, and familiarity judgment, respectively, on later study-test cycles of a recall experiment.

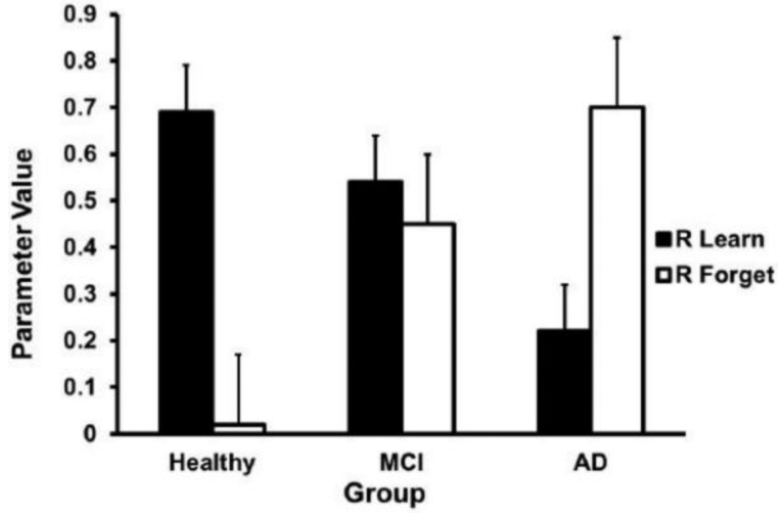

Figure 4.

Differentiation of ADAMS subject groups by reconstructive retrieval. R Learn is the average probability of learning to reconstruct words on the CERAD recall task, over the three study-test cycles. R Forget is the average probability of forgetting how to reconstruct words on the CERAD recall task, over a 5 min filled delay.

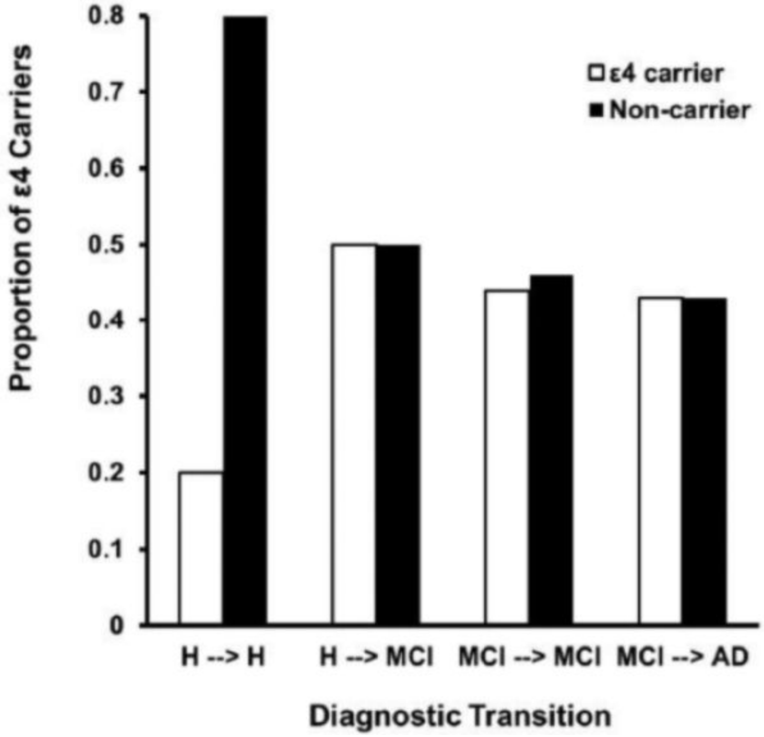

Figure 5.

Prediction of future disease by the ε4 allele of the *APOE* genotype.

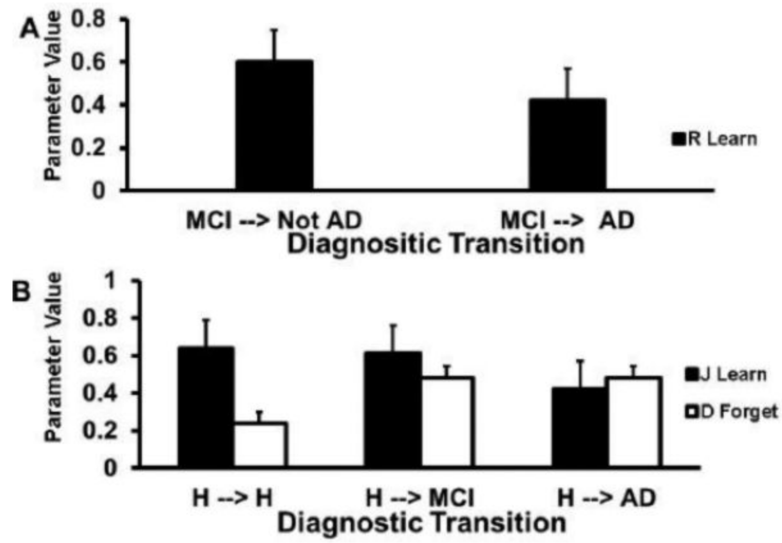

Figure 6.

Prediction of future disease by reconstructive retrieval (*R*), direct access retrieval (*D*), and familiarity judgment (*J*). In Panel A, *R* Learn is the average probability of learning to reconstruct words on the CERAD recall task, over the three study-test cycles. In Panel B, *D* Forget is the average probability of forgetting how to directly access words on the CERAD recall task, over a 5 min filled delay, and *J* Learn is the average probability of learning that reconstructed words on the CERAD recall tasks are familiar enough to be output, over the three study-test cycles.

Table 1

Three Procedures that Measure Reasoning Under Risk and Uncertainty

Details	**Task**
	Decision framing
Scenario	Imagine that the U.S. is preparing for the outbreak of an unusual Asian disease, which is expected to kill 600 people. Two alternative programs to combat the disease have been proposed. Assume that the exact scientific estimate of the consequences of the programs are as follows:
Gain frame	If Program A is adopted, 200 people will be saved. If Program B is adopted, there is 1/3 probability that 600 people will be saved, and 2/3 probability that no people will be saved. Which of the two programs would you favor?
Loss frame	If Program C is adopted 400 people will die. If Program D is adopted there is 1/3 probability that nobody will die, and 2/3 probability that 600 people will die. Which of the two programs would you favor?
	Allais paradox
Decision 1	Choose between the following prospects:
	A. Win $1 million with 100% probability.
	B. Win $1 million with 89% probability or nothing with 1% probability or $5 million with 10% probability
Decision 2	Choose between the following prospects:
	C. Win nothing with 89% probability or $1 million with 11% probability.
	D. Win nothing with 90% probability or $5 million with 10% probability.
	Centipede game
Scenario	You will play a game for real payoffs in which you are paired with another person. The game consists of eight trials. You (or your partner) make choices, on alternating trials. On odd number trials, you may decide whether to stop and take the stated payoffs or continue to the next trial, on which your partner will decide whether to stop take the stated payoffs or continue to the next trial.
Payoff structure	

	1	2	3	4	5	6	7	8
You:	$1.5	$1	$6	$4	$24	$16	$96	$64
Partner:	$5	$3	$2	$12	$8	$48	$32	$192

Table 2

Instructions for Making Remember/Know About Items Recognized as Old (Rajaram, 1993)

Judgment	Instructions
Remember	If your recognition of the word is accompanied by a conscious recollection of its prior occurrence in the study list, then write "R." "Remember" is the ability to become consciously aware again of some aspect or aspects of what happened or what was experienced at the time the word was presented (e.g., aspects of the physical appearance of the word, or of something that happened in the room, or of what you were thinking and doing at the time). In other words, the "remembered" word should bring back to mind a particular association, image, or something more personal from the time of study, or something about its appearance or position (i.e., what came before or after that word).
Know	"Know" responses should be made when you recognize that the word was in the study list but you cannot consciously recollect anything about its actual occurrence or what happened or what was experienced at the time of its occurrence. In other words, write "K" (for "know") when you are certain of recognizing the words but these words fail to evoke any specific conscious recollection from the study list.
	To further clarify the difference between these two judgments (i.e., "R" vs. "K"), here are a few examples. If someone asks for your name, you would typically respond in the "know" sense without becoming consciously aware of anything about a particular event or experience; however, when asked the last movie you saw, you would typically respond in the "remember" sense, that is, becoming consciously aware again of some aspects of the experience. If you have any questions regarding these judgments, please ask the experimenter.

Table 3

Retrieval processes that are measured by the modeling tool with repeated recall data and delayed recall data

Parameter	Process Definition
	Direct access
D_1	The probability that a verbatim trace of an item's presentation list can be accessed after
	the first study cycle
D_2	For any item whose verbatim trace could not be accessed following prior study cycles, the probability that its verbatim trace can be accessed after the current study cycle
	Reconstruction
R_1	For any item for whose verbatim trace cannot be accessed after the first study cycle, the probability that it can be reconstructed after that study cycle
R_2	For any item for whose verbatim trace cannot be accessed after the current study cycle and that could not be reconstructed after prior study cycles, the probability that it can be reconstructed after the current study cycle
	Familiarity judgment
J_1	For any item that is reconstructed following the first study cycle, the probability that the reconstruction is judged to be familiar enough to recall
J_2	For any item that is reconstructed following any study cycle after the first one, the probability that the reconstruction is judged to be familiar enough to recall